Understanding the Link Between
Brain Activation, Choice, and Attitude Change
for European Americans and East Asians

By

Steven Tompson

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
(Psychology)
in the University of Michigan
2016

Doctoral Committee:

Professor Shinobu Kitayama, Chair
Assistant Professor Allison N. Earl
Associate Professor Emily B. Falk, University of Pennsylvania
Professor Israel Liberzon

DEDICATION

I dedicate this dissertation to my wife Sarah Huff for her unwavering emotional and motivational support of me (and this research), and to my parents Susan and Steven Tompson for instilling in me a love of learning, a drive to pursue my passions, and a work ethic to make all these things possible.

ACKNOWLEDGEMENTS

First, I would like to acknowledge my advisor and committee chair, Dr. Shinobu Kitayama. You took a chance on me when I was an undergrad with limited research experience who had never taken more than an introductory neuroscience class. Over the past seven years you've provided guidance, a little bit of tough love, and pushed me to be the best researcher I could be. I am absolutely a better writer, researcher, and thinker because of your support.

To my dissertation committee members Dr. Israel Liberzon, Dr. Emily Falk, and Dr. Allison Earl, thank you for serving on my committee and making time in your incredibly busy schedules to provide guidance and feedback on my dissertation. Over the past few years, you all have played instrumental roles in my development as a researcher and have provided invaluable advice, support, and guidance throughout my graduate career.

Thank you to members of the Gene x Culture Interaction group, Culture & Cognition group, HAILab, and Communication Neuroscience Lab, who allowed me to workshop ideas pertaining to this research numerous times over the past few years. I especially would like to thank Dr. Israel Liberzon, Dr. Carolyn Yoon, Dr. Tony King, and Sarah Huff for valuable input on virtually all phases of this dissertation, including design, data collection, fMRI data pre-processing, data analyses, and interpretation of the data.

Also, thank you to Orphan Lab, including Josh Wondra, Joe Bayer, and Dave Hauser. You guys are always good for a sharp intellectual conversation and a good laugh. It's been great being able to workshop ideas with you and relax after a long day of research.

Thank you to Mike Angstad, Teresa Pegors, Hannah Faye Chua, and Nita Patel for their technical support. You were instrumental in helping with task design, data prep and pre-processing, and helping me puzzle through the more complex analyses.

Thank you to Risa Gotlib and the whole Tiny Buddha Yoga crew for keeping me grounded, calm, and focused throughout the past year. Finding your studio and being able to go to yoga and clear my mind has been life changing and surely helped me get through the dissertation writing process.

To my friends Lauren Reed, Joe Bayer, Sarah Huff, and Josh Wondra, thank you for being true friends, helping me celebrate the good times, distracting me when I'm frustrated, or helping me (often over a beer) to puzzle through ideas and issues in my graduate education, research, and life. I owe you all infinite beers for your support.

Thank you to my family (both old and new!) for supporting me throughout my graduate education. Even if you didn't always understand what I was talking about, you always were there to lend a supportive ear. Thank you to my parents for always pushing me to work hard in school and find my passion (who knew that school would actually be my passion?).

Last but certainly not least, thank you to my wife Sarah. You are already included in many of the earlier acknowledgements and played a crucial role in supporting the academic and intellectual part of this research. But your most important contribution has to be your loving support of me over the past few years. I tend to throw myself into my work, which often results in euphoria when even the shortest line of code works, but also anguish when I can't figure out why I keep getting the same error message or why my results look weird. You celebrate my small triumphs and cushion my subsequent crashes when things don't go well. Without you none of this would be possible.

Table of Contents

LIST OF TABLES

TABLE

LIST OF FIGURES

FIGURE

ABSTRACT

How do people make difficult choices, and how does the decision process influence subsequent attitudes towards the choice options? Moreover, does culture influence decision-making and attitude change? My dissertation addresses these questions using neuroimaging data from individuals who evaluated choice options before and after making difficult choices either for the self or a close friend. In Study 1, I measured neural activation during decision-making and found that brain regions involved in self-processing and reward processing predicted attitude change for European Americans but not East Asians. Moreover, regions involved in conflict detection and negative arousal were recruited when people made difficult (versus easy) choices for the self and a close friend, whereas mentalizing regions were recruited when people made difficult choices for a close friend (versus self choices). In Study 2, I found that post-choice connectivity between regions involved in self-processing predicted attitude change. In Study 3, I found that European Americans represented information about choice outcome (chosen versus rejected) in self-processing regions, whereas East Asians represented information about choice outcome in mentalizing regions. Both European Americans and East Asians represented information about choice target (self versus friend) in both self-processing and mentalizing brain regions. The current work provides evidence for key brain regions and networks that support decision-making and attitude change for both the self and close others. This research advances understanding of how culture shapes the way in which people evaluate choice options and make choice.

CHAPTER I

Introduction

Decision-making can be quite difficult, involving complex information about the choice options. People can experience intense anxiety, decision paralysis (where they are so anxious they actually can't make a choice), and intense regret after making a choice. The New York Times Bestseller list is frequently populated with self-help books designed to help people make better choices in their life, but there are still many unresolved questions about decision-making. How do people process choice information? What are the boundary conditions for these processes? That is, are the same (or different) neural processes recruited when people make choices for themselves as well as for close others? Are the same (or different) neural processes recruited for individuals from different cultures? And how does this decision process influence attitudes towards the choice options? The current work utilizes neuroimaging to examine these important questions and provides evidence for key brain regions and networks that support decision-making and attitude change for both the self and close others.

Decision-making can be difficult, in part, because choice options involve multiple attributes and evaluating which option is the "best" can be ambiguous and subjective. When purchasing a new car, should you purchase the most popular car, the safest car, or the one with the best gas mileage? There are many publically available metrics to help evaluate attributes such as popularity, safety, and fuel efficiency, but what if you care more about popularity with your friends and family than national popularity? For many decision attributes, there isn't an objective metric that can be used to inform the decision, and thus the decision becomes subjective and

open to the interpretation of the chooser. In turn, this ambiguity can lead to conflicting thoughts, attitudes, and beliefs about which option to choose, as well as decision-related negative arousal (e.g., anxiety, fear, and regret).

How Do People Make Difficult Choices?

In his initial formulation of cognitive dissonance theory, Leon Festinger argued that people experience conflict (e.g., conflict between choice options) as negatively arousing and are motivated to reduce this negative arousal (called dissonance). One way in which people have been shown to resolve choice-related dissonance is to shift their attitudes and preferences towards the choice options (Brehm, 1956; DeWall, Chester, & White, 2015; Kitayama & Tompson, 2015). For example, imagine a recent PhD graduate who must choose between job offers at two elite universities with similar starting salaries, teaching requirements, and startup research funding. Because the choice is difficult, the graduate should experience negative affect, which in turn motivates the graduate to search for positive features that are distinctive to one school (and absent in the other school). She could identify that University A has a newer research center, and this process of searching for positive distinctive features should lead the graduate to prefer University A more and University B less than they initially did. Moreover, this search process should reduce response conflict between the two options and enable the graduate to make a decision.

Research on Choice and Attitudes

Since Festinger's original formulation, many researchers have theorized different processes that might be involved in influencing dissonance arousal, facilitating dissonance-reducing attitude change, or both (Aronson, 1969; Bem, 1967; Cooper & Fazio, 1984; Elliot & Devine, 1994; Gawronski, Bodenhausen, & Becker, 2007; Eddie Harmon-Jones, Amodio, &

Harmon-Jones, 2010; Kitayama & Tompson, 2015; Steele, 1988; Stone & Cooper, 2001). Much of this work has centered around two primary psychological processes—self-appraisal and negative arousal.

Negative arousal is one of the core components of dissonance theory, but there has been surprisingly little research directly examining the role of negative arousal in motivating choice-related attitude change (although there have been a number of studies on how negative arousal relates to other types of attitude change; e.g., Elliot & Devine, 1994; Harmon-Jones, 2000). The most direct evidence for the role of negative arousal in motivating choice-related attitude change comes from DeWall and colleagues, who found that individuals who have taken a pain reliever show reduced attitude change, suggesting that pain associated with making a difficult choice is involved in choice-related attitude change (DeWall et al., 2015).

Daryl Bem argued that, rather than changing their attitudes to reduce negative arousal, people simply infer that, because they chose one option over another, they must prefer that option more (Bem, 1967). This account, called self-perception theory, does not require conflict or negative arousal to explain choice-related attitude change and instead posits that thoughts about one's past behaviors are the primary drivers of choice-related attitude change.

Other theorists have argued that self-appraisal modulates dissonance, rather than replaces it (as Bem argued). Concern about making the right choice (especially when the choice is difficult) should be greater when individuals are making a choice that is important or connected to the self and these choices should elicit greater threat to one's perceived view of the self as a competent, intelligent decision-maker (Aronson, 1969; Steele, 1988). Thus, when a choice involves a greater degree of self-appraisal, individuals experience greater dissonance, and are

more likely to increase their preference for the chosen option and decrease their preference for the rejected option.

However, this research has typically been limited to measuring preferences before and after a difficult choice and inferring dissonance arousal based on the amount of choice-related attitude change that occurs. As a result, most of this research has assumed that dissonance reducing attitude change occurs after the choice has already been made, and has ignored how negative arousal and/or self-appraisal occurring during the choice might also be involved in promoting choice-related attitude change. This assumption is due, at least in part, to the difficulty of measuring psychological processes occurring during a relatively short (less than 5 seconds) decision. However, one promising avenue through which to study in-choice processes is neuroimaging. Neuroimaging can provide a window into this choice period, allowing researchers to test what psychological and neural processes might be going on during the choice that facilitate the decision and subsequent attitude change.

Biosocial Model of Affective Decision-Making

Recently, we proposed a biosocial model of affective decision-making that outlines how in-choice processes might contribute to choice-related attitude change (Kitayama & Tompson, 2015). The biosocial model distinguishes between two levels of processing: in-choice affective processing and post-choice cognitive processing. When presented with two equally attractive options to choose between, individuals experience negative affect and conflict over which option to choose (i.e., dissonance). Recent work in neuroimaging has identified the dorsal anterior cingulate cortex (dACC) and anterior insula (aINS) as being involved in conflict detection (Shenhav, Straccia, Cohen, & Botvinick, 2014), feelings of physical and social pain (Eisenberger & Lieberman, 2004), and feelings of disappointment and regret (Chua, Gonzalez, Taylor, Welsh,

& Liberzon, 2009). In support of the hypothesis that dissonance entails activation of dACC and aINS, Kitayama and colleagues (2013) found greater in-choice activation in these two areas when participants make difficult (as compared to easy) choices.

Once dissonance is aroused (and dACC and aINS are activated), it will motivate additional processing to resolve conflict between the choice options and reduce negative arousal. At this initial, pre-cognitive level, choices are made on the basis of the reward values of choice options, which are associated with striatal processing (including ventral striatum [vSTR], caudate, and midbrain). Thus, one way in which an individual could resolve choice-related conflict is to update reward values of choice options by focusing on positive features of one option (that are not present in the other option). Through this additional evaluation of the choice options, the individual develops more positive attitudes towards one option than the other, which motivate the response selection. During the choice, activity in vSTR and posterior cingulate cortex (PCC) predicts choice-related attitude change (Jarcho, Berkman, & Lieberman, 2011; Kitayama, Chua, Tompson, & Han, 2013). These regions are implicated in anticipated reward and incentive processing (Berridge, Robinson, & Aldridge, 2009; Knutson, Taylor, Kaufman, Peterson, & Glover, 2005; Pearson, Hayden, Raghavachari, & Platt, 2009) as well as self-referential processing and episodic memory (Sajonz et al., 2010; van der Meer, Costafreda, Aleman, & David, 2010). This evidence is consistent with the claim of the biosocial model that the decision maker evaluates and updates reward options in order to make a difficult choice and reduce conflict and negative arousal.

The second, more cognitive component of the biosocial model occurs after the choice and serves to reinforce the choice. Once the choice has been made, it is cognitively represented, connected with abstract representations of the self as well as with past episodes and/or future

plans relevant to the choice. This cognitive component corresponds to post-choice attitude change mechanisms that are postulated by existing social psychological theories that include cognitive mechanisms involving self, episodic memories, and future planning (Aronson, 1969; Bem, 1967; Cooper & Fazio, 1984; Festinger, 1957; Gawronski et al., 2007; Steele, 1988), although these studies rarely provide any direct evidence for mediating cognitive mechanisms. Of all of these cognitive mechanisms, self-processing may be the most promising for further understanding post-choice attitude change through neuroimaging. Extensive social neuroscience research has been valuable in identifying regions that are reliably activated when individuals think, make judgments, and recall memories about the self, including mPFC and PCC/Pcu (Chua et al., 2011; Denny, Kober, Wager, & Ochsner, 2012; Northoff et al., 2006b; van der Meer et al., 2010). I therefore anticipate that post-choice self-processing should predict choice-related attitude change.

Choice Target

Most of the research discussed above focuses on choices made for the self. But, oftentimes the choices that we make involve others as well, whether it is a choice made for a group (e.g., buying a TV for your house that your roommates will also use), a gift purchased for a friend, or even a personal choice that impacts someone else (e.g., choosing a job that impacts your spouse). Choices made for others involve many of the same decision processes and thus recruit many of the same brain regions, but they can also be more complex and require considering the perspective and mental state of others. As a result, previous research has found that choices for others recruit many of the same brain regions involved in choices for the self (e.g., mPFC, PCC, and vSTR; Hare, Camerer, Knoepfle, & Rangel, 2010; Janowski, Camerer, & Rangel, 2013; Jung, Sul, & Kim, 2013; Zaki, Lopez, & Mitchell, 2014), but they also recruit

regions involved in thinking about the mental states of others (i.e., mentalizing) including temporoparietal junction (TPJ; Hare et al., 2010; Janowski et al., 2013; Jung et al., 2013). However, none of these studies examined these neural processes across cultures, nor did they test attitude change to see whether neural activation for self and friend choices might relate to attitude change for chosen and rejected options.

Based on the analysis above, I expect that regions involved in detecting conflict (dACC), negative arousal (aINS), reward processing (vSTR), mentalizing (TPJ), and self-processing (mPFC and PCC) should be recruited when people make difficult choices, and should also facilitate choice-related attitude change. In Chapter 2, I will focus on average levels of activation (i.e., univariate activation) within these brain regions to examine how these brain regions are involved in decision-making and attitude change. In Chapter 3, I will expand beyond single-region activation and test whether connectivity between brain regions (specifically, between mPFC and PCC) is related to attitude change. Finally, in Chapter 4, I will use multivariate analyses to test whether patterns of activation within these regions represent information about the choice options.

Beyond Univariate Activation

Analyzing the patterns of activation within and between brain regions can advance our understanding of the psychological processes underlying choice and attitude change. Traditional neuroimaging analyses focusing on average or peak activation within a single region fail to capture complex patterns of activation across brain regions (Haxby, 2012), and thus analyses that examine connectivity between regions as well as patterns of activation within brain regions will be important for understanding how brain activity facilitates decision-related attitude change.

Moreover, multivariate patterns within a brain region are thought to track firing patterns of clusters of neurons within that brain region more closely than univariate activation, and thus more strongly represent how that brain region is processing and representing information (Mur, Bandettini, & Kriegeskorte, 2009). This research is the first to examine cultural differences in neural representations of choice information, and thus provides an exciting new window into how people from different cultures process choice information.

Choice and Culture

An additional goal of the current project is to examine potential boundary conditions of the relationship between brain activation, choice, and attitude change.. Specifically, do people from different cultures recruit the same (or different) brain regions when making choices for the self and a close friend? People from collectivistic cultures (e.g. Japan, Korea, and China) tend to view the self as interdependent: connected with others, embedded in social relationships, and defined primarily by relational characteristics such as social duties and roles (Markus & Kitayama, 1991). People from collectivistic cultures are more likely to choose shared (vs. unique) options for themselves (H. Kim & Markus, 1999), be motivated to work hard at a task for a close other (Iyengar & Lepper, 1999; Na & Kitayama, 2012), and perceive choice as an opportunity to strengthen one's social relationships (H. S. Kim & Sherman, 2007). In contrast, people from individualistic cultures (e.g. the United States) tend to view the self as independent: unique, separate from others, and defined primarily by internal features such as personality traits and preferences (Markus & Kitayama, 1991). For people from individualistic cultures, choices are seen as expressive of one's internal, self-defining features (Iyengar & Lepper, 1999; Kim & Sherman, 2007; Na & Kitayama, 2012) and people from individualistic cultures may therefore see choice as an action that is self-defining.

Moreover, as compared to people from collectivistic cultures, people from individualistic cultures perceive more choices in everyday behavior (Savani, Markus, Naidu, Kumar, & Berlia, 2010), are more likely to change their attitudes following a difficult choice (Kitayama, Snibbe, Markus, & Suzuki, 2004), choose unique (vs. common) options for themselves (Kim & Markus, 1999), and view choice as an opportunity to express their personal preferences more (Savani, Markus, & Conner, 2008). Thus, people from individualistic cultures should primarily make choices that are driven by internal factors (e.g., personal preferences), whereas people from collectivistic cultures should primarily make choices that are grounded in the social context and influenced by norms and preferences of close others (Markus & Kitayama, 2003; Riemer, Shavitt, Koo, & Markus, 2014). Extending this reasoning, neural processes that are involved in evaluating information about the self and one's personal preferences should be strongly involved in decision-making for people from individualistic cultures. By contrast, neural processes that integrate information about social context and others' preferences should be strongly involved in decision-making for people from collectivistic cultures.

Consistent with the above analysis, recent research has found that people from individualistic cultures are more likely to recruit regions involved in thinking about and evaluating the self when making social judgments (e.g., judging whether a trait adjective describes the self and/or a close friend), whereas people from collectivistic cultures are more likely to recruit regions involved in taking the perspective of others when making social judgments (Han & Ma, 2014; Ma et al., 2012). For example, Danish individuals are more likely to recruit mPFC when thinking about and evaluating the self whereas Chinese individuals are more likely to recruit TPJ when thinking about and evaluating the self (Ma et al., 2012). Additionally, a recent meta-analysis found that these cultural differences extend to other types of

social judgments, such that people from individualistic cultures are more likely to recruit mPFC whereas people from collectivistic cultures are more likely to recruit TPJ when making social judgments (Han & Ma, 2014). I believe that these same patterns of cultural differences (greater TPJ activation for people from collectivistic cultures and greater mPFC activation for people from individualistic cultures) might extend to consumer choices as well.

Research Aims and Hypotheses

The current research aims to address five primary questions:

Question #1: How do people make difficult choices?

Question #2: Do in-choice neural processes influence attitude change?

Question #3: Do post-choice neural processes influence attitude change?

Question #4: Are the same neural processes involved for personal and social choices?

Question #5: Are the same neural processes involved for people from individualistic and collectivistic cultures?

In Chapter 2, I use neuroimaging to address Questions #1, 2, 4 and 5. I examine neural activation while individuals from the United States and East Asia make choices for themselves and a close friend. I hypothesize that mentalizing regions should be more involved in decision-making for East Asians, whereas self-processing regions should be more involved in decision-making for European Americans.

Chapter 3 expands upon Chapter 2 by addressing how post-choice processes contribute to attitude change (Question #3). In Chapter 3, I use neuroimaging to examine whether changes in univariate activation as well as changes in connectivity are related to attitude change. I hypothesize that activation of and connectivity between regions involved in self-processing

should increase from pre-choice to post-choice, and this change in connectivity should predict choice-related attitude change.

Chapter 4 expands upon the first two papers by examining whether multivariate patterns of activation in regions involved in self-processing, mentalizing, or reward processing represent information about the choice options (Question #1). In Chapter 4, I also examine whether these representations change from pre-choice to post-choice, and whether there are cultural differences in neural representations of choice information (Question #5). I hypothesize that self-processing regions should be more strongly involved in representing choice information for European Americans, whereas mentalizing regions should be more strongly involved in representing choice information for East Asians.

CHAPTER II

Neural processes underlying decision-making and attitude change

Introduction

How do people make difficult choices when the options are seemingly equal? And how does this decision process influence subsequent attitudes towards the choice options? Researchers in the social sciences have shown that, after people make a difficult choice between two equally preferred choice options, they will increase their preference for the chosen option and decrease their preference for the rejected option (Brehm, 1956). Recent neuroscientific evidence suggests that this attitude change process might occur during the choice itself, and may facilitate the decision-making process (Jarcho et al., 2011; Kitayama et al., 2013; Kitayama & Tompson, 2015). However, the vast majority of this research focuses on a very narrow breadth of choices and social contexts—namely, consumer choices made for the self by European Americans. It is therefore unclear whether these same processes might extend to other types of choices (e.g., choices for close others) and other social contexts (e.g., choices made by people from different cultures). In order to fully understand how neural processes contribute to decision-making and attitude change, it is also necessary to identify the conditions under which these processes are more or less likely to be involved. The current research extends earlier work by examining what brain regions are recruited when European Americans and East Asians make difficult choices and how these neural processes influence choice-related attitude change.

Additionally, this work examines whether these neural processes differ when making choices for the self or a close friend. In doing so, this work addresses questions about the generalizability of previous work to other types of choices and social contexts, as well as enables us to better understand how people from different cultures make choices.

The Relationship between Choice and Attitudes

Early work on decision-making and attitude change measured attitudes towards choice options both before and after participants made a choice between two similarly preferred options. This work established that attitudes towards the option that was chosen increased from the pre-choice rating period to the post-choice rating period, whereas attitudes towards the rejected option decreased (called spreading of alternatives [SoA]; Brehm, 1956). Subsequent work has argued that SoA is motivated by a drive to reduce negative affect associated with conflict between the two choice options. For example, individuals who have taken a pain reliever show reduced choice-related attitude change, suggesting that pain associated with making a difficult choice is involved in choice-related attitude change (DeWall et al., 2015).

How Do People Make Difficult Choices?

One interesting omission from the above theorizing about the relationship between choice and attitude change concerns how the choice itself is made. Most theories postulate that some combination of self-evaluation and motivation to reduce negative arousal lead individuals to shift their attitudes once the choice has been made (Aronson, 1969; Steele, 1988). However, none of these studies explain how individuals come to the original choice. That is, if participants truly prefer both choice options equally, how do they make the choice? Our recently proposed biosocial model of affective decision-making outlines the neural processes that might facilitate difficult choices between two equally preferred options and in the process lead to shifts in

attitudes towards the choice options (Kitayama & Tompson, 2015). The biosocial model distinguishes between two levels of processing. The first, more affective component occurs while the choice is being made, whereas the second, more cognitive component of the biosocial model occurs after the choice and serves to reinforce the choice. The current study focuses on the initial affective component.

When presented with two equally attractive options to choose between, individuals initially experience negative affect and conflict over which option to choose (i.e, dissonance). Recent work in neuroimaging has identified the dorsal anterior cingulate cortex (dACC) and anterior insula (aINS) as being involved in conflict detection (Shenhav et al., 2014), feelings of physical and social pain (Eisenberger & Lieberman, 2004), and feelings of disappointment and regret (Chua et al., 2009). Moreover, Kitayama and colleagues (2013) found greater in-choice activation in these two areas when participants make difficult (as compared to easy) choices. Although these regions are by no means exclusively involved in conflict detection and negative arousal, this evidence does support the hypothesis that difficult choices lead to greater dissonance.

Once a difficult choice arouses dissonance (and dACC and aINS are activated), the chooser will be motivated to reduce this negative arousal. One way to reduce choice-related dissonance is to identify positive incentives that are unique to one of the available choice options (Kitayama & Tompson, 2015). Through this process, the individual develops more positive attitudes towards one option than the other, which is reflected in reward processing in ventral striatum (Jarcho et al., 2011; Kitayama et al., 2013; Kitayama & Tompson, 2015).

One limitation of the above research is that it has focused almost exclusively on one type of choice—namely consumer choices made for the self. Although this form of choice is common

and prevalent, choices may also be made where the self is not the primary target of the choice. For example, one may choose a gift for someone important. Research on cognitive dissonance has found that individuals also display choice-related attitude change for choices made for close others (Hoshino-Browne et al., 2005; Kimel, Grossmann, & Kitayama, 2012) and individuals can experience vicarious conflict and discomfort when they witness someone else engage in attitude-inconsistent behaviors (Cooper & Hogg, 2007; Norton, Monin, Cooper, & Hogg, 2003). Thus, there is some evidence that cognitive dissonance and choice-related attitude change might extend to difficult choices made for a close other, with the same neural processes involved for choices made when the self is not the primary target of the choice. However, seemingly identical behavioral outcomes can often result from potentially different underlying psychological or neural processes (Amodio, 2010; Lieberman, 2010), and it therefore also remains possible that the strength of these underlying factors differs as a function of choice type or social context. So it remains an open question whether the neural processes outlined in the biosocial model and identified in previous research extend to other types of choices.

Choice Target

There are a few studies that have examined brain regions involved in making a decision for someone other than the self. These studies have consistently found both similarities and differences in the brain regions recruited for choices made for the self and choices made for someone else (Hare et al., 2010; Janowski et al., 2013; Jung et al., 2013; Zaki et al., 2014). Regions involved in processing reward, including ventromedial prefrontal cortex (vmPFC) and ventral striatum (vSTR), track both subjective value to the chooser as well as others' preferences (Janowski et al., 2013; Zaki et al., 2014). This suggests that neural circuits identified as being involved in making choices for the self may also be recruited when making choices for someone

else. Other research has noted dissociations between choices made for the self and choices made for someone else, such that people are more likely to recruit brain regions involved in mentalizing or taking another person's perspective (Hare et al., 2010; Janowski et al., 2013; Jung et al., 2013). Importantly, most of these studies involve decisions whether to gamble for a stranger (i.e., bet a stranger's money) and did not examine these processes for more ecologically valid choices (e.g., whether to buy a product as a gift for a friend). Moreover, none of these studies examined neural activation across cultures, nor did they test attitude change to see whether neural activation for self and friend choices might relate to attitude change for chosen and rejected options.

Culture and Choice

Recent research has also found that culture influences activation of the same mentalizing regions implicated in making choices for others. Specifically, people from collectivistic cultures such as Japan (who view the self as interdependent and fundamentally intertwined with others; Markus & Kitayama, 1991) are more likely to recruit mentalizing brain regions such as dorsal medial prefrontal cortex (dmPFC) and TPJ when making social judgments such as inferring the mental states of others or thinking about the self (Han & Ma, 2014; Ma et al., 2012). By contrast, people from individualistic cultures such as the United States (who view the self as independent, autonomous, and distinct from others; Markus & Kitayama) are more likely to recruit brain regions involved in thinking about and evaluating the self, such as ventral medial prefrontal cortex (vmPFC) when making the same types of social judgments (Han & Ma, 2014; Ma et al., 2012). Moreover, people from individualistic cultures are more likely to view choice as an opportunity to express one's preferences, attitudes, and other self-relevant features (Kim & Sherman, 2007) and shift their attitudes more when making personal choices for themselves

(Hoshino-Browne et al., 2005), whereas people from collectivistic cultures are more likely to shift their attitudes when making social choices for close others (Hoshino-Browne et al., 2005).

Based on this previous research, I expect that people from collectivistic cultures should be more likely to recruit mentalizing regions when making a choice for a close other, whereas people from individualistic cultures should be more likely to recruit brain regions involved in thinking about the self when making a choice for a close other. To date, no research has directly tested whether cultures differ in the degree to which they recruit mentalizing and self-related brain regions when making decisions. Moreover, none of these studies have examined what brain regions might be involved in promoting choice-related attitude change.

Present Research

The current study has four primary aims.

Recent work has raised concerns over the reliability and replicability of fMRI research, suggesting that many previous findings could be false positives (Barch & Yarkoni, 2013; de la Vega, Chang, Banich, Wager, & Yarkoni, 2016). Thus, the first aim of this study was to replicate Kitayama and colleague's work on the brain regions involved in making difficult choices. I hypothesize that brain regions involved in detecting cognitive conflict and negative arousal should be recruited when making difficult (versus easy) choices.

The second aim was to replicate Kitayama and colleague's work on the brain regions associated with attitude change. I hypothesize that attitude change should be associated with activation in vSTR and PCC.

The third aim was to investigate whether recruitment of these regions is moderated by choice target, and the fourth aim was to investigate whether recruitment of these regions is moderated by culture. I hypothesize that there should be common, overlapping neural processes that are

shared by self and friend choices made by European Americans and East Asians as well as dissociable neural processes that are distinct to self versus friend choices and choices made by European Americans versus East Asians. Specifically, activation in vSTR and PCC should predict attitude change for European Americans. To the extent that the mechanisms proposed in the biosocial model extend to East Asians, the same effects should be present for East Asians. Additionally, I hypothesize that both European Americans and East Asians should recruit brain regions involved in detecting cognitive conflict and negative arousal when making difficult choices. Moreover, European Americans should be more likely to recruit brain regions involved in thinking about the self, whereas East Asians should be more likely to recruit brain regions involved in mentalizing.

Method

Participants

One-hundred nine undergraduates at the University of Michigan participated in the experiment[1]. Fourteen participants were excluded due to data quality issues (two due to excessive head motion, four due to missing responses to greater than 25% of trials, four due to brain artifacts, and four due to scanner issues). Analysis was performed on the remaining 95 participants (50 European Americans [32 females and 18 males], 45 East Asians [28 females and 17 males]). All participants had normal or corrected-to-normal vision and had no history of head injury or psychiatric illness. Participants received $60 as well as one of the posters they chose for themselves and one of the posters they chose for their friend (to give as a gift to their friend). All participants gave written consent and the Institutional Review Board at the University of Michigan approved the procedure.

[1] These participants were recruited as part of a larger study of cross-cultural variations (n=635).

Stimuli

Participants were presented with images of posters taken from AllPosters.com's most popular posters lists (top lists of Art, Nature, Movies, Music, Celebrities, and Sports posters) and pretested to be equally liked by European American and East Asian college students.

Procedure

Participants completed three tasks while having their brain activity measured in an fMRI scanner. Employing a similar paradigm as past fMRI work on choice-related attitude change (Jarcho et al., 2011; Kitayama et al., 2013; Sharot, De Martino, & Dolan, 2009), participants first completed a pre-choice rating task, followed by a choice task, and finally they completed the post-choice rating task (see Figure II.1 for details). In the pre-choice rating task, participants were presented with a set of 72 posters to evaluate for themselves and a different set of 72 posters to evaluate for their friend. Posters were presented one at a time and for each poster participants were instructed to either rate how much they like the poster or rate how much their friend would like the poster on a 5-point scale (1=least likeable, 5=most likeable). Assignment of the two sets of 72 posters to the self and friend conditions were counterbalanced such that half of the participants evaluated Set A for the self and Set B for the friend and the other half were given the opposite. Trials were pseudo-randomized such that participants saw between 2-6 trials of a given trial type (i.e., choice for the self vs. choice for the friend) in a row to reduce frame-switching burden. I also included a cue (jittered presentation between 1 and 4 sec, M=1.875, SD=1.064) prior to each trial indicating whether the next trial would be a self trial or friend trial.

In the choice task, participants were presented with pairs of posters and selected one poster from each pair. For half of the pairs participants selected the poster that they wanted (i.e., self choices), and for the other half they selected a poster for their friend (i.e., friend choices).

Because I was primarily interested in neural activation involved in making difficult choices that are more likely to elicit negative arousal, conflict, and choice-related attitude change, I used an algorithm to pair posters together such that each participant made 30 "difficult-self" choices, 30 "difficult-friend" choices, 6 "easy-self" choices, and 6 "easy-friend" choices. First, 12 posters from the self condition were paired together such that each pair of posters were rated in the pre-choice rating task at least 2 apart in the self condition (e.g., the participant rated one poster a "4" and the other poster a "2"). Next, the remaining 60 posters from the self condition were paired together into 30 pairs of posters such that each pair of posters were rated nearly identical in the pre-choice rating task (e.g., the participant rated both posters a "4" or rated one poster a "4" and the other poster a "3"). This pairing procedure was then repeated for the posters in the friend condition (i.e., posters where the participant rated how much their friend liked the poster). The choice task also included a pseudo-randomized trial order such that participants saw between 2-6 trials of a given trial type. I also included a cue (jittered presentation between 1 and 4 sec, M=1.875, SD=1.064) prior to each trial indicating whether the next trial would be a self trial or friend trial. It was explained that one of the 36 posters chosen by the participant for themselves would be randomly selected and given to the participant at the end of the session and one of the 36 posters chosen for the friend would also be randomly selected and the participant could give the poster to their friend as a gift; so the choices were incentive compatible with real values. Finally, in the post-choice rating task, participants repeated the rating task described above for the pre-choice rating task.

Behavioral Analyses

In order to examine attitude change from pre-choice to post-choice, I first computed three change scores. Previous research has identified that individuals typically increase their

preference for the chosen option and decrease their preference for the rejected option as a function of making a choice. Change in preference for the chosen option and change in preference for the rejected option were computed as the post-choice rating minus the pre-choice rating, such that positive values indicate an increase in preference and negative values indicate a decrease in preference. Spreading of Alternatives (SoA) is computed as the change in chosen options minus the change in rejected options in each choice pair. I then computed the average SoA score, average change for chosen options, and average change for rejected options for each subject and each condition (difficult self, difficult friend, easy self, and easy friend).

Using the average attitude change scores, I first tested whether there was an overall attitude change difference for difficult and easy choices. I next conducted a mixed ANOVA to test whether culture (between-subjects factor) or choice target (within-subjects factor) influenced attitude change for difficult choices. I also examined whether attitude change was significant for European Americans and East Asians separately, and whether there was significant attitude change for difficult self and difficult friend choices separately.

fMRI Data Acquisition

Scanning was performed using a Philips 3 Tesla MRI scanner (Phillips Medical Systems, Andover, Massachusetts). T2*-weighted echo planar gradient-recall echo volumes (echo time=30ms, repetition time=2000ms, 64x64 matrix, flip angle=90 degree, field of view=220mm, 42 contiguous 3mm axial slices per volume), were acquired for each task. Five additional volumes were discarded at the beginning of each run to allow for stabilization of the MRI signal. The pre-choice and post-choice rating tasks were each split into three runs (each lasting six minutes and twelve seconds) and the choice task was split into two runs (each lasting 5 minutes and twelve seconds). A high-resolution T1-weighted structural image (echo time=4.6ms,

repetition time=9.8ms, 256x200 matrix, flip angle=8 degrees, field of view=256x256x180 (mm), 180 contiguous 1mm sagittal slices per volume) was also obtained to provide for more precise anatomical localization.

Functional MRI data analysis

Preprocessing of data was completed using SPM8 (Wellcome Department of Cognitive Neurology, London, UK). Functional volumes were slice time corrected to account for temporal differences in slice acquisition time, realigned to correct for head motion, and spatially normalized to a standard template based upon the Montreal Neurological Institute (MNI) reference brain using VBM8 toolbox and DARTEL high dimensional warping, and spatially smoothed using a 5-mm Gaussian kernel. Runs were excluded from analysis if their head motion exceeded 3mm maximum Euclidean displacement during the run, and participants were excluded from analysis if greater than 50% of their runs had excessive head motion.

I conducted three primary analyses to examine neural activation during difficult choices. First, I examined whether neural activation during difficult choices might predict subsequent attitude change. Second, I examined whether any brain regions are more strongly recruited when people make difficult (versus easy) choices, collapsing across self and friend choices. Third, I compared neural activation for difficult-self choices with activation during difficult-friend choices, to examine whether the target of the choice (self versus friend) influences neural activation involved in making difficult choices. For all analyses, single-subject analysis were performed using standard GLM analysis (Worsley, Evans, Marrett, & Neelin, 1992; Worsley, Poline, Friston, & Evans, 1997) in SPM8, focusing on modeling neural activation during the choice task.

Analysis 1: Association with attitude change. The primary goals of Analysis 1 were to (i) replicate previous work by Kitayama et al. (2014) and Jarcho et al. (2011) and (ii) see whether these same patterns extend to friend choices and/or East Asian participants. This first analysis focused on the association between trial-by-trial neural activation and attitude change for chosen options during difficult choices and included regressors for each condition (difficult-self and difficult-friend), parametric regressors for the association with attitude change for each condition, and nuisance regressors consisting of the motion correction parameters and their derivatives from the realignment preprocessing step. First-level contrasts examined whether attitude change was correlated with trial-by-trial changes in neural activation in each condition within each subject, as well as whether the relationship between these measures and neural activation differs for difficult-self and difficult-friend trials. All first-level subject data was then entered into a second-level general linear model. In order to replicate Kitayama et al. and Jarcho et al., I first examined whether there were any clusters of activation associated with attitude change in PCC or vSTR. I defined anatomical ROIs within PCC and vSTR using the automated anatomical labeling in SPM8's WFU PickAtlas toolbox (Maldjian, Laurienti, Kraft, & Burdette, 2003) and identified clusters of activation within those regions that were significantly correlated with attitude change using a small-volume correction ($p<.05$). In order to minimize bias when subsequently examining effects of culture or choice target, these regions were identified analyzing all 95 subjects and collapsing across difficult-self and difficult-friend choices.

I then conducted ROI analyses using the peak voxels identified in the initial small-volume search in order to examine whether there are any differences in the association between vSTR and PCC and attitude change as a function of culture or choice target. I created spheres of 5mm diameter around the voxel of maximum activation in each cluster using MarsBaR. I then

extracted betas in both difficult-self and difficult-friend trials (as well as overall average across all difficult trials) from each ROI and entered these extracted betas into two-sample t-tests comparing European Americans and East Asians to test for cultural differences in each ROI.

Analysis 2: Difficult versus easy choices. The primary goals of Analysis 2 were to (i) identify brain regions associated with making difficult (versus easy) choices and (ii) see whether these same patterns are influenced by choice target or ethnicity. This second analysis focused on differences in neural activation for difficult versus easy choices and included regressors for each condition (difficult-self, difficult-friend, easy-self, easy-friend) and nuisance regressors consisting of the motion correction parameters and their derivatives from the realignment preprocessing step. First-level contrasts focused on differences in activation for difficult versus easy choices (collapsing across self and friend choices) as well as examining differences in activation for difficult-self versus easy-self and difficult-friend versus easy-friend choices separately. All first-level subject data was then entered into a second-level general linear model. In order to examine whether there are common brain regions underlying difficult-self and difficult-friend choices made by European Americans and East Asians, I first conducted an exploratory whole-brain analysis using an FDR-corrected $p<.05$ threshold.

Using the regions identified in the whole-brain analysis, I then conducted a region-of-interest (ROI) analysis to examine whether there are any differences in activation as a function of choice target or ethnicity. I created spheres of 5mm diameter around the voxel of maximum activation in each cluster, in each contrast using MarsBaR. I then extracted betas from each ROI and computed difference scores between difficult and easy choices. I then entered these difference scores into one-sample t-tests to test for differences as a function of choice difficulty. I

also entered the difference scores into two-sample t-tests comparing European Americans and East Asians to test for cultural differences in each ROI.

Analysis 3: Self versus friend choices. The primary goals for Analysis 3 were to (i) identify brain regions preferentially recruited during self choices or friend choices and (ii) see whether these same patterns are influenced by ethnicity. This third analysis focused on differences in neural activation for self versus friend choices and included regressors for each condition (difficult-self, difficult-friend, easy-self, easy-friend) and nuisance regressors consisting of the motion correction parameters and their derivatives from the realignment preprocessing step. First-level contrasts focused on differences in activation for difficult-self versus difficult-friend trials. All first-level subject data was then entered into a second-level general linear model. In order to examine whether there are common brain regions underlying difficult-self and difficult-friend choices made by European Americans and East Asians, I first conducted an exploratory whole-brain analysis using an FDR-corrected $p<.05$ threshold.

Using the regions identified in the whole-brain analysis, I then conducted region-of-interest (ROI) to examine whether there are any differences in activation as a function of choice target or ethnicity. I created spheres of 5mm diameter around the voxel of maximum activation in each cluster, in each contrast using MarsBaR. I then extracted betas from each ROI and computed difference scores between self and friend choices. I then entered these difference scores into one-sample t-tests to test for differences as a function of choice target. I also entered the difference scores into two-sample t-tests comparing European Americans and East Asians to test for cultural differences in each ROI.

Results

Behavioral Results

I first examined changes in behavioral ratings of the choice options. When I examined attitude change across all 95 participants and choice types, I found that SoA ($t(94)= 22.89$, $p<.001$), increase in preference for chosen options ($t(94)= 16.74$, $p<.001$), and decrease in preference for rejected options ($t(94)= 16.93$, $p<.001$) were all significantly greater for difficult than easy choices (see Figure II.2). For difficult choices, there was a significant SoA ($t(94)=26.85$, $p<.001$). This was due to a significant increase in preference for chosen options from pre-choice ($M= 2.89$, $SD= 0.52$) to post-choice ($M= 3.10$, $SD= 0.54$; $t(94)= 10.02$, $p< .001$), whereas preference for rejected options decreased from pre-choice ($M= 2.84$, $SD= 0.52$) to post-choice ($M= 2.57$, $SD= 0.53$; $t(94)= -13.09$, $p< .001$). For easy choices, there was actually a negative SoA ($t(94)= -12.76$, $p<.001$), due to a decrease in preference for chosen options from pre-choice ($M= 4.76$, $SD= 0.41$) to post-choice ($M= 4.50$, $SD= 0.47$; $t(94)= -9.34$, $p< .001$) and an increase in preference for rejected options from pre-choice ($M= 1.23$, $SD= 0.50$) to post-choice ($M= 1.47$, $SD= 0.52$; $t(94)= 9.72$, $p< .001$), although this effect appears to be primarily driven by ceiling and floor effects, respectively[2].

I next examined whether attitude change differed as a function of culture or choice target. SoA was not influenced by choice target (self versus friend; $F(1,93) = 1.84$, $p = .178$), culture (European American versus East Asian; $F(1,93) = 0.31$, $p = .579$) or the interaction between choice target and culture ($F(1,93) = 0.38$, $p = .540$). I also examined attitude change separately for difficult self and difficult friend choices. SoA was significant for difficult self choices ($t(94)= 22.59$, $p<.001$), and this was due to both significant increases in preferences for the chosen

[2] The average pre-choice ratings for the chosen and rejected options suggest that this change might be due to a ceiling and floor effect, such that if most pre-choice easy pairs consisted of 1s and 5s, random variation in the higher rated option (the 5) would lead to an average decrease in preference ratings whereas random variation in the lower rated option (the 1) would lead to an average increase in preference ratings.

options ($t(94)= 8.16$, $p<.001$) as well as significant decreases in preference for the rejected options ($t(94)= 10.33$, $p<.001$). SoA was also significant for difficult friend choices ($t(94)= 21.21$, $p<.001$), and this was due to both significant increases in preferences for the chosen options ($t(94)= 8.94$, $p<.001$) as well as significant decreases in preference for the rejected options ($t(94)= 12.46$, $p<.001$).

When breaking down the results by cultural group, it appears that this effect is robust for both European Americans and East Asians. Specifically, SoA was significant for European Americans making difficult self choices ($M= 0.44$, $SD= 0.17$; $t(49)= 18.67$, $p< .001$) and difficult friend choices ($M= 0.49$, $SD= 0.22$; $t(49)= 16.17$, $p< .001$), and this was due to significant increases in preferences for the chosen options (difficult self: $t(49)= 10.01$, $p<.001$; difficult friend: $t(49)= 7.62$, $p<.001$) as well as significant decreases in preference for the rejected options (difficult self: $t(49)= 7.93$, $p<.001$; difficult friend: $t(49)= 10.05$, $p<.001$). For East Asians, there was also significant SoA for difficult self choices ($M= 0.48$, $SD= 0.23$; $t(44)= 14.07$, $p< .001$) and difficult friend choices ($M= 0.50$, $SD= 0.24$; $t(44)= 13.755$, $p< .001$), and this was due to significant increases in preferences for the chosen options (difficult self: $t(44)= 3.90$, $p<.001$; difficult friend: $t(44)= 5.41$, $p<.001$) as well as significant decreases in preference for the rejected options (difficult self: $t(44)= 7.11$, $p<.001$; difficult friend: $t(44)= 7.68$, $p<.001$).

fMRI Results

I conducted three sets of fMRI analyses. First, I examined whether neural activation during difficult choices might predict subsequent attitude change. Second, I compared neural activation for difficult-self and difficult-friend choices (relative to easy-self and easy-friend choices) to examine whether any brain regions are more strongly recruited when people make difficult (versus easy) choices. Third, I compared neural activation for difficult-self choices with

activation during difficult-friend choices, to examine whether the target of the choice (self versus friend) influences neural activation involved in making difficult choices.

Analysis 1: Association with attitude change. I first tested whether neural activation during difficult choices was correlated with attitude change. To replicate previous work (Jarcho et al., 2011; Kitayama et al., 2013), I ran a small-volume corrected ($p<.05$) search for clusters of activation in vSTR and PCC, examining the association between attitude change and neural activation across all 95 subjects making both difficult-self and difficult-friend choices. Consistent with past work, there was an overall effect such that attitude change for the chosen options was positively correlated with activation in left vSTR (coordinates=[-9,17,-8], t=2.80, k=23) and PCC (coordinates=[3,-40,13], t=3.73, k=229; see Figure II.2).

Using the peak voxels identified above, I then conducted an ROI analysis to examine whether there were any cultural differences in the association between neural activation and attitude change. When collapsing across difficult-self and difficult-friend trials, the association between vSTR activation and attitude change was greater for European Americans than East Asians, although this effect was only marginally significant (see Table II.1 for statistics). The overall association between neural activation in vSTR and attitude change appears to be primarily driven by European Americans, such that European Americans show a significant association between vSTR and attitude change for both difficult-self (see Table II.1 and Figure II.3) and difficult-friend choices, whereas East Asians do not show a significant association between vSTR activation and attitude change in difficult-self or difficult-friend choices. There were also no significant differences in the association between vSTR and attitude change as a function of choice target.

There were no significant differences between European Americans and East Asians in the association between PCC activation and attitude change (see Table II.1 for statistics). There was a significant overall association between neural activation in PCC (across both difficult-self and difficult-friend trials) and attitude change for European Americans and a marginally significant association for East Asians (see Table II.1 and Figure II.3). This appears to be primarily driven by difficult-friend choices, such that both European Americans and East Asians show significant relationship between PCC activation and attitude change for difficult-friend choices. European Americans showed a similar trend for difficult-self choices, but this effect was not statistically significant. There were also no significant differences in the association between PCC activation and attitude change as a function of choice target for European Americans. For East Asians, the association between PCC activation and attitude change was significantly stronger for difficult-friend choices than difficult-self choices.

Analysis 2: Neural activation during difficult choices. Next, I examined what brain regions are recruited when European Americans and East Asians make difficult choices for the self and a close friend. When I examined neural activation across all 95 participants and choice types, I found that dACC, left aINS, and right aINS were all recruited more during difficult choices than during easy choices (FDR-corrected $p<.05$; see Figure II.4). Additional regions recruited more during difficult (versus easy) choices include visual cortex, fusiform, parahippocampal gyrus, all of which are involved in attention and object processing (see Table II.2). I next extracted average activation from the three primary functional ROIs (left aINS, and right aINS, posterior MFC, and dACC) and examined whether activation in these regions differed as a function of culture or choice target (see Figure II.5). There were no main effects of culture or choice target, nor an interaction between the two for any of the functional ROIs. In

fact, recruitment of these three regions appears to be robust across both self choices and friend choices, such that European Americans and East Asians show greater activation in dACC and aINS for difficult-self than easy-self choices, as well as for difficult-friend than easy-friend choices (see Table II.3 for summary).

Analysis 3: Comparison of self and friend choices. Finally, I examined how neural activation during difficult choices might differ for self and friend choices. When examining patterns of activation that are greater for self than friend choices, object processing regions including fusiform and parahippocampal gyrus as well as executive control regions including right dorsolateral prefrontal cortex (dlPFC) were recruited more for self than friend choices (FDR-corrected $p<.05$; see Table II.4 and Figure II.6). Using functional ROI analyses, I then examined activation in these ROIs for each cultural group separately. Both European Americans and East Asians showed greater activation of fusiform and parahippocampal gyrus for self choices than friend choices, although this effect appears to be slightly stronger in European Americans (see Table II.5 and Figure II.7).

When examining patterns of activation that are greater for friend than self choices, brain regions including precuneus, PCC, TPJ, and temporal pole were significantly more active for friend than self choices (FDR-corrected $p<.05$; see Table II.6 and Figure II.8). Using functional ROI analysis to further interrogate the data, there was not a significant difference in the degree to which East Asians and European Americans recruit precuneus, PCC, TPJ, and temporal pole when making choices for the friend (versus self), although the difference between friend and self appears to be slightly stronger for East Asians (see Table II.7 and Figure II.9).

Discussion

This research shows that in-choice activation of vSTR and PCC predicts choice-related attitude change. While the overall relationships between vSTR and PCC activation and attitude change appear to be robust when collapsing across cultural groups and choice types, further exploration suggests some potential boundary conditions to this overall effect. For vSTR, there is a stronger association between vSTR activation and attitude change for European Americans than East Asians, although this effect is only marginally significant. Interestingly, the association between PCC activation and attitude change appears to be stronger for friend choices for both European Americans and East Asians, although the difference is only significant for East Asians.

Despite these apparent differences in brain regions involved in attitude change, both cultural groups appear to recruit similar brain regions when making difficult choices for the self and a close friend. dACC, aINS, parahippocampal gyrus, fusiform gyrus, and dlPFC are recruited more during difficult (versus easy) choices, regardless of cultural background or choice target. Furthermore, PCC and TPJ are recruited more during difficult choices for a close friend (versus difficult-self choices). Recruitment of PCC and TPJ during difficult-friend choices appears to be primarily driven by East Asians, although the direct cultural comparison was not statistically significant.

Culture and Attitude Change

The current work is the first to directly compare neural activation involved in choice-related attitude change for people from different cultures. Previous work on the effect of choice on attitudes suggests that people from East Asian cultures should be more likely to justify social choices by increasing their positive attitudes towards chosen options and decreasing their attitudes towards rejected options and less likely to justify personal choices (compared to

European Americans; Hoshino-Browne et al., 2005; Kitayama, Snibbe, Markus, & Suzuki, 2004). Based on this behavioral finding, previous researchers have inferred that Americans must experience more dissonance for personal choices than Asians, whereas Asians must experience more dissonance for social choices than Americans. Interestingly, in the current work European Americans and East Asians show similar degrees of dissonance (measured by dACC and aINS activation), but differ in the brain regions that predict attitude change.

In the current study, I replicate earlier work showing that activation of vSTR and PCC predict choice-related attitude change. For vSTR, European Americans show a significant positive association between attitude change and neural activation for both self and friend choices. vSTR is involved in processing and updating subjective value of choice options (Bartra, McGuire, & Kable, 2013; Knutson, Rick, Wimmer, Prelec, & Loewenstein, 2007; Knutson et al., 2005), and therefore European Americans appear to be increasing their preference for the chosen option by updating reward value in the brain. Interestingly, this effect extends to choices made for a close friend, suggesting that European Americans update their own subjective valuation of the choice options even when making a choice for a close other.

PCC, on the other hand, predicted attitude change for both European Americans and East Asians. Interestingly, in this case the effect appears to be primarily driven by friend choices. Both European Americans and East Asians show a significant positive association between PCC activation and attitude change for friend choices but not for self choices (although there is a slight trend for European Americans). While this finding was somewhat unexpected, average PCC activation was also significantly greater for difficult-friend than for difficult-self choices for both European Americans and East Asians. PCC is involved in recalling autobiographical memories (Qin et al., 2012; Sajonz et al., 2010; van der Meer et al., 2010) and some theorists

have argued that it may integrate autobiographical memories into social judgments about the self as well as close others (van der Meer et al., 2010). Thus, one interpretation of these findings is that both European Americans and East Asians are thinking about past experiences associated with the close friend, and the more these memories are recruited the greater the subsequent attitude change. Previous theorists have argued that attitude change is stronger when choices are self-relevant (Aronson, 1969; Steele, 1988) and therefore friend choices that recruit more self-relevant cognitions or memories should lead to greater attitude change. However, this same logic could be extended to self choices as well, and it is therefore somewhat surprising that there was not a significant association between PCC and attitude change for self choices. It is possible that choices made for the self are evaluated more in terms of personal preferences and less in terms of direct connections to past experiences, in which case I would anticipate that PCC activation is weaker for self choices and should be less linked to attitude change.

Common brain regions involved in making difficult choices

Replicating prior work (Jarcho et al., 2011; Kitayama et al., 2013), I find that European Americans recruit brain regions involved in conflict detection, negative arousal, visual attention, and executive control when making difficult choices for the self. Moreover, these same brain regions are also recruited when European Americans make difficult friend choices and when East Asians make difficult choices for the self and a close friend. In fact, these regions were reliably recruited to similar degrees whenever individuals made a difficult (versus easy) choice, regardless of choice target or culture. This suggests that involvement of dACC, aINS, parahippocampal gyrus, fusiform gyrus, and dlPFC is robust across choice types and cultures. These regions are frequently recruited when individuals engage in effortful, task-related processing, and therefore these findings suggest that individuals are putting more cognitive effort

into evaluating choice options for difficult choies, regardless of their cultural background or who the choice target is. The recruitment of dACC and aINS during difficult choices is also consistent with cognitive dissonance theory and the biosocial model, which argue that people experience choice-related conflict as negatively arousing (Festinger, 1957; Kitayama & Tompson, 2015).

Dissociations between self and friend choices

Although there appear to be common brain regions involved in making difficult choices for both the self and a close friend, there are also some dissociations in the brain regions that are recruited for difficult self and friend choices. Specifically, people from both individualistic and collectivistic cultures are more likely to recruit brain regions involved in object processing and visual attention when making choices for the self, whereas they are more likely to recruit brain regions involved in autobiographical memory retrieval and mentalizing when making choices for a friend. This suggests that difficult choices made for the self are more likely to involve attending to physical features of the choice options and evaluating the objects, whereas difficult choices made for a close friend are more likely to involve taking the friends' perspective and thinking about which options the friend might prefer.

One might initially anticipate that autobiographical memories about the chooser's past experiences should be recruited more for self choices than friend choices. However, it is possible that self choices are more about evaluating the object relative to one's personal preferences, and don't require introspection about one's past experiences. By contrast, most individuals have not internalized their friend's preferences, and thus choices made for a close friend require additional recruitment of information about the friend (including past experiences with the friend that may shed light on their preferences).

There are some potentially interesting are subtle trend-level differences in how these brain regions are recruited by European Americans and East Asians for self versus friend choices (although it is important to note that these differences were not statistically significant). European Americans seem to show slightly greater activation of object processing and visual attention regions for self (versus friend) choices, whereas East Asians show reduced activation of these regions for self (versus friend) choices. This is consistent with behavioral work suggesting that European Americans are more concerned with making the best objective choice for the self, whereas East Asians are more likely to make holistic choices that consider multiple factors, such as opinions of close others (Savani, Cho, Sooyun, & Morris, 2014).

When focusing on the functional ROI analyses, it does appear that European Americans recruit mentalizing regions when making friend (versus self) choices, although this activation is still reduced compared to East Asians. This is consistent with a recent meta-analysis, which found that East Asians are more likely than Westerners to recruit mentalizing regions when making social judgments (Han & Ma, 2014) and suggests that East Asians may be taking the perspective of their friends more when making choices for their friend. European Americans seem to be considering their friends' perspective as well, although potentially less than East Asians.

One important caveat is that many of these differences are qualitative—I find a significant effect for one group but not the other, but the direct cultural comparison is marginally significant or non-significant. The effect sizes of the cultural differences in our study are predominantly in the 0.15 to 0.30 range and always trend in the same direction, suggesting that there is a reliable, albeit small, effect of culture on neural activation. The fact that these results are consistent with past work on social and non-social judgments (Han & Ma, 2014) supports our

conclusion that these effects are real (but small). It is also possible that these effects might be larger if East Asian participants were tested in East Asia; all East Asian participants in this study had spent fewer than 7 years in the United States, but it is still possible that the East Asian participants had become acculturated and adjusted to American culture.

Conclusion

In summary, the current study examines how European Americans and East Asians make difficult choices for the self and a close friend. I find that brain regions involved in reward processing facilitate choice-related attitude change for European Americans making choices for themselves and a close friend, but not East Asians. Moreover, brain regions involved in effortful processing, conflict detection, and negative arousal underlie difficult choices regardless of culture or choice type, whereas brain regions involved in object processing are preferentially involved for self choices and brain regions involved in autobiographical memory and mentalizing are preferentially involved for friend choices. This research advances our understanding of how people make difficult choices and boundary conditions influencing the brain regions involved in decision-making and choice-related attitude change.

Table II.1. Functional ROI results for brain regions correlated with attitude change.

		Mean (SD)	t-statistic	df	p-value
Correlation with Attitude Change for All Subjects					
Left Ventral Striatum (vSTR)					
	All Choices	0.04 (0.17)	2.41	94	.018
	Self Choices	0.05 (0.23)	2.32	94	.023
	Friend Choices	0.03 (0.23)	1.34	94	.183
	Self versus Friend	0.02 (0.30)	0.71	94	.478
Posterior Cingulate Cortex (PCC)					
	All Choices	0.08 (0.21)	3.53	94	<.001
	Self Choices	0.04 (0.30)	1.20	94	.231
	Friend Choices	0.12 (0.27)	4.22	94	<.001
	Self versus Friend	0.08 (0.38)	2.04	94	.045
Correlation with Attitude Change for European Americans					
Left Ventral Striatum (vSTR)					
	All Choices	0.07 (0.14)	3.77	49	<.001
	Self Choices	0.08 (0.21)	2.82	49	.007
	Friend Choices	0.07 (0.19)	2.44	49	.018
	Self versus Friend	0.02 (0.29)	0.42	49	.675
Posterior Cingulate Cortex (PCC)					
	All Choices	0.09 (0.20)	3.13	49	.003
	Self Choices	0.06 (0.27)	1.60	49	.115
	Friend Choices	0.11 (0.28)	2.78	49	.008
	Self versus Friend	0.05 (0.39)	0.90	49	.374
Correlation with Attitude Change for East Asians					
Left Ventral Striatum (vSTR)					
	All Choices	0.01 (0.20)	0.26	44	.798
	Self Choices	0.02 (0.24)	0.59	44	.559
	Friend Choices	-0.01 (0.27)	0.15	44	.883
	Self versus Friend	0.03 (0.32)	0.58	44	.567
Posterior Cingulate Cortex (PCC)					
	All Choices	0.07 (0.23)	1.92	44	.061
	Self Choices	0.01 (0.33)	0.20	44	.842
	Friend Choices	0.12 (0.26)	3.21	44	.002
	Self versus Friend	0.11 (0.37)	2.05	44	.046
Cultural Difference in Correlation with Attitude Change					
Left Ventral Striatum (vSTR)					
	All Choices		1.86	77.47	.066
	Self Choices		1.32	87.01	.190

	Friend Choices	1.49	78.71	.140
	Self versus Friend	0.17	88.99	0.869
Posterior Cingulate Cortex (PCC)				
	All Choices	0.46	86.73	.645
	Self Choices	0.83	85.43	.409
	Friend Choices	0.20	93.00	.844
	Self versus Friend	0.80	92.87	.426

Table II.2. Brain regions recruited significantly more for difficult than easy choices.

Region	Coordinates (x,y,z)	Parameter Estimates	Cluster Sizes
Difficult > Easy (All Subjects)			
L Fusiform	(-30,-52,-17)	11.30	7378
R Fusiform	(30,-46,-17)	10.53	
L Visual Cortex	(-33,-85,16)	7.97	
R Visual Cortex	(30,-79,16)	7.93	
L IFG	(-33,32,-11)	5.58	
L IFG	(-39,26,19)	4.89	
L aINS	(-27,29,1)	4.84	
R aINS	(33,26,1)	3.94	
L pMFC	(-6,17,46)	8.49	1463
L Precentral Gyrus	(-30,-28,55)	8.26	
L dACC	(-6,26,34)	5.74	
R IFG	(48,29,16)	6.21	89
R pINS	(-33,-19,19)	5.73	263
L dmPFC	(-6,56,28)	3.21	31
Difficult > Easy (European American Only)			
L Fusiform	(-27,-49,-14)	9.60	8063
R Fusiform	(30,-52,-11)	8.71	
L Visual Cortex	(-33,-85,-13)	6.87	
R Visual Cortex	(33,-88,16)	6.46	
L pINS	(-42,-28,16)	5.96	
R Putamen	(21,-1,-8)	4.97	
Thalamus	(-9,-19,7)	4.86	
L Putamen	(-24,5,4)	4.82	
L aINS	(-33,17,7)	3.47	
R aINS	(33,26,1)	3.49	
L pMFC	(-6,14,46)	8.37	1817
L Precentral Gyrus	(-30,-25,55)	7.69	
dACC	(12,26,31)	6.20	
R IFG	(48,29,16)	4.03	31
R pINS	(42,-4,13)	3.93	239
L dmPFC	(-15,32,46)	3.34	46
L TP	(-42,5,-35)	3.26	24
R Precentral Gyrus	(60,5,22)	3.24	124
R Fusiform	(33,-7,-35)	3.17	16
L Caudate	(-12,20,7)	2.69	7

Difficult > Easy (East Asian Only)			
L Fusiform	(-33,-52,-17)	7.94	1580
L Visual Cortex	(-33,-85,4)	5.99	
R Fusiform	(30,-49,-17)	6.99	1466
R Visual Cortex	(36,-76,25)	5.71	
L pMFC	(-6,17,46)	4.86	100
L dACC	(-9,26,37)	3.88	
R IFG	(45,29,16)	4.85	84
L Precentral Gyrus	(-30,-28,55)	4.76	116
L IFG	(-36,11,28)	4.37	114
L dmPFC	(-15,35,46)	4.21	28
L pINS	(-33,-16,19)	4.12	17
L IFG	(-33,32,14)	3.57	30
L aINS	(-27,26,1)	3.22	
R dACC	(12,23,37)	3.51	7
Thalamus	(-15,-16,1)	3.36	14
L dmPFC	(-9,59,16)	3.35	8

Table II.3. Functional ROI results for Difficult > Easy contrast.

		Mean (SD)	t-statistic	df	p-value
Difficult > Easy for European Americans					
Left Anterior Insula (aINS)					
	Self	0.11 (0.36)	2.19	49.00	0.033
	Friend	0.10 (0.34)	2.04	49.00	0.047
Right Anterior Insula (aINS)					
	Self	0.11 (0.43)	1.84	49.00	0.072
	Friend	0.19 (0.43)	3.09	49.00	0.003
Posterior Medial Frontal Cortex (pMFC)					
	Self	0.32 (0.41)	5.53	49.00	<0.001
	Friend	0.23 (0.35)	4.63	49.00	<0.001
Dorsal Anterior Cingulate Cortex (dACC)					
	Self	0.27 (0.48)	3.99	49.00	<0.001
	Friend	0.19 (0.47)	2.85	49.00	0.006
Difficult > Easy for East Asians					
Left Anterior Insula (aINS)					
	Self	0.10 (0.34)	2.05	44.00	0.046
	Friend	0.08 (0.28)	1.86	44.00	0.070
Right Anterior Insula (aINS)					
	Self	0.10 (0.49)	1.32	44.00	0.194
	Friend	0.07 (0.39)	1.23	44.00	0.226
Posterior Medial Frontal Cortex (pMFC)					
	Self	0.27 (0.53)	3.36	44.00	0.002
	Friend	0.20 (0.44)	3.00	44.00	0.004
Dorsal Anterior Cingulate Cortex (dACC)					
	Self	0.17 (0.54)	2.11	44.00	0.041
	Friend	0.12 (0.43)	1.85	44.00	0.071
Cultural Difference in Difficult > Easy contrast					
Left Anterior Insula (aINS)					
	Self		0.11	92.79	0.913
	Friend		0.31	92.40	0.757
Right Anterior Insula (aINS)					
	Self		0.17	88.22	0.869
	Friend		1.40	93.00	0.164
Posterior Medial Frontal Cortex (pMFC)					
	Self		0.53	82.18	0.599
	Friend		0.36	83.42	0.718
Dorsal Anterior Cingulate Cortex (dACC)					
	Self		0.97	88.71	0.335

	Friend	0.76	92.96	0.451

Table II.4. Brain regions recruited significantly more for self than friend choices

Region	Coordinates (x,y,z)	Parameter Estimates	Cluster Sizes
Self > Friend (All Subjects)			
R Fusiform	(27,-52,-8)	5.37	112
R paraHC	(36,-25,-17)	3.98	10
L paraHC	(-24,-37,-11)	5.12	172
L Fusiform	(-27,-58,-11)	5.05	
r IFG	(45,32,16)	4.55	38
L Hippocampus	(-21,-13,-20)	4.44	30
L Visual Cortex	(-33,-82,-25)	4.06	9
R IPL	(36,-61,46)	3.83	7
R paraHC	(30,-19,-23)	3.82	21
Self > Friend (European American Only)			
No significant clusters at FDR-corrected p<.05			
Self > Friend (Asian Only)			
No significant clusters at FDR-corrected p<.05			

Table II.5. Functional ROI results for Self > Friend contrast

	Mean (SD)	t-statistic	df	p-value
Self > Friend for European Americans				
Left Fusiform	0.12 (0.24)	3.44	49.00	0.001
Right Fusiform	0.12 (0.22)	3.92	49.00	<0.001
Left Parahippocampal Gyrus	0.12 (0.20)	4.46	49.00	<0.001
Right Parahippocampal Gyrus	0.12 (0.21)	3.89	49.00	<0.001
Self > Friend for East Asians				
Left Fusiform	0.12 (0.25)	3.34	44.00	0.002
Right Fusiform	0.12 (0.26)	3.19	44.00	0.003
Left Parahippocampal Gyrus	0.08 (0.19)	2.75	44.00	0.009
Right Parahippocampal Gyrus	0.05 (0.20)	1.75	44.00	0.087
Cultural Difference in Self > Friend contrast				
Left Fusiform		0.11	91.49	0.913
Right Fusiform		0.08	85.87	0.938
Left Parahippocampal Gyrus		1.20	92.70	0.234
Right Parahippocampal Gyrus		1.51	92.73	0.134

Table II.6. Brain regions recruited significantly more for friend than self choices.

Region	Coordinates (x,y,z)	Parameter Estimates	Cluster Sizes
Friend > Self (All Subjects)			
L PCC/Pcu	(-3,-64,31)	6.92	434
L TPJ	(-45,-61,19)	5.61	159
L dlPFC	(-21,53,22)	4.16	89
L TP	(-60,-10,-14)	3.97	15
L TPJ	(-51,-31,25)	3.78	37
L SPL	(-21,-52,61)	3.62	27
R TPJ	(54,-28,28)	3.51	20
Friend > Self (European American Only)			
No significant clusters at FDR-corrected $p<.05$			
Friend > Self (Asian Only)			
L PCC/Pcu	(-6,-61,28)	7.46	341
L TPJ	(-39,-58,16)	4.78	72
L dmPFC	(-6,62,-19)	4.88	32

Table II.7. Functional ROI results for Friend > Self contrast.

	Mean (SD)	t-statistic	df	p-value
Friend > Self for European Americans				
PCC/Pcu	0.18 (0.37)	3.36	49.00	0.024
Left TPJ #1	0.10 (0.20)	3.40	49.00	0.001
Left TPJ #2	0.06 (0.17)	2.26	49.00	0.028
Left TP	0.09 (0.29)	2.25	49.00	0.029
Right TPJ	0.09 (0.28)	2.33	49.00	0.024
Friend > Self for East Asians				
PCC/Pcu	0.31 (0.32)	6.44	44.00	<0.001
Left TPJ #1	0.15 (0.21)	4.64	44.00	<0.001
Left TPJ #2	0.07 (0.17)	2.85	44.00	0.007
Left TP	0.22 (0.52)	2.82	44.00	0.007
Right TPJ	0.10 (0.28)	2.39	44.00	0.021
Cultural Difference in Friend > Self contrast				
PCC/Pcu		1.86	92.88	0.066
Left TPJ #1		1.19	90.53	0.237
Left TPJ #2		0.48	92.28	0.631
Left TP		1.46	66.81	0.150
Right TPJ		0.13	91.92	0.894

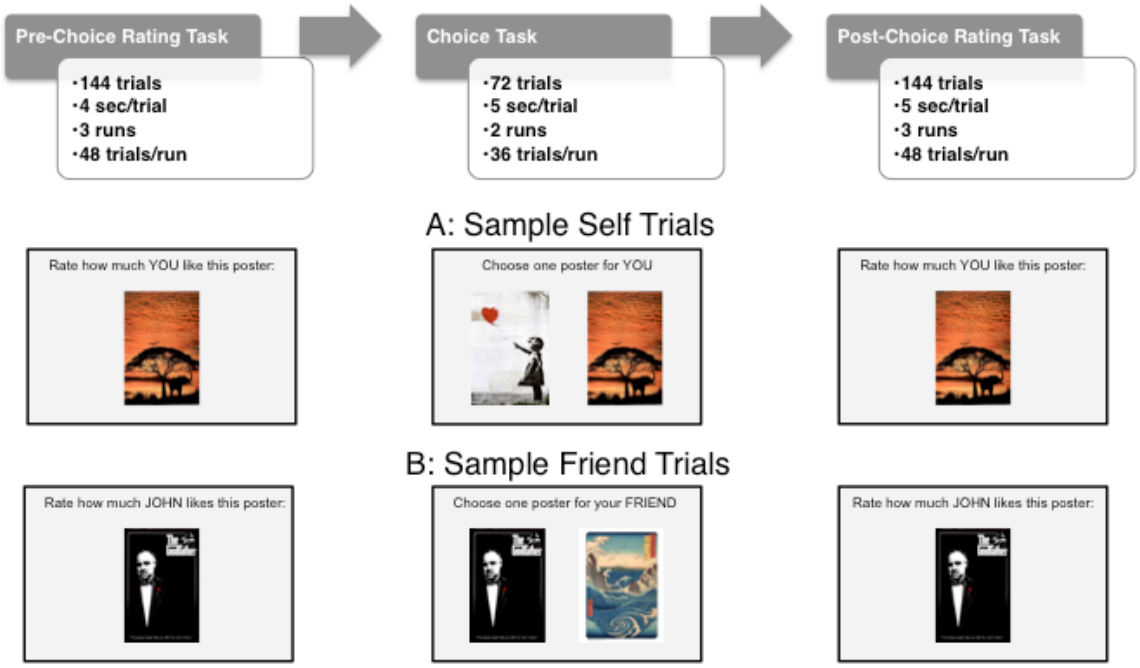


Figure II.1. Participants completed three tasks during the fMRI scan. During the pre-choice rating task participant saw a 1-4 seconds jittered fixation screen, followed by a 1-4 seconds jittered cue screen indicating whether the next trial would be a self trial or friend trial, followed by a 4 second window where they were shown a poster and rated on a 5-point scale how much they liked the poster (for self trials) or how much their friend liked the poster (for friend trials). During the choice task participant saw a 1-4 seconds jittered fixation screen, followed by a 1-4 seconds jittered cue screen indicating whether the next trial would be a self trial or friend trial, followed by a 5 second window where they were shown two posters and chose one of the two posters either for themselves or for their friend. Finally, participants completed the post-choice rating task which was identical to the pre-choice rating task.

Figure II.2. Brain regions correlated with attitude change for chosen options. Results displayed at small-volume corrected p<.05.

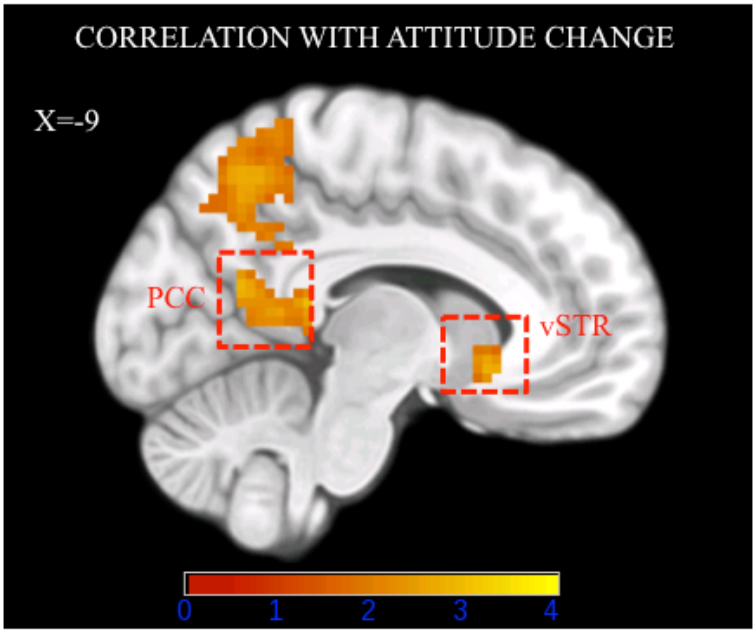


Figure II.3. Functional ROI results from brain regions correlated with attitude change for chosen options.

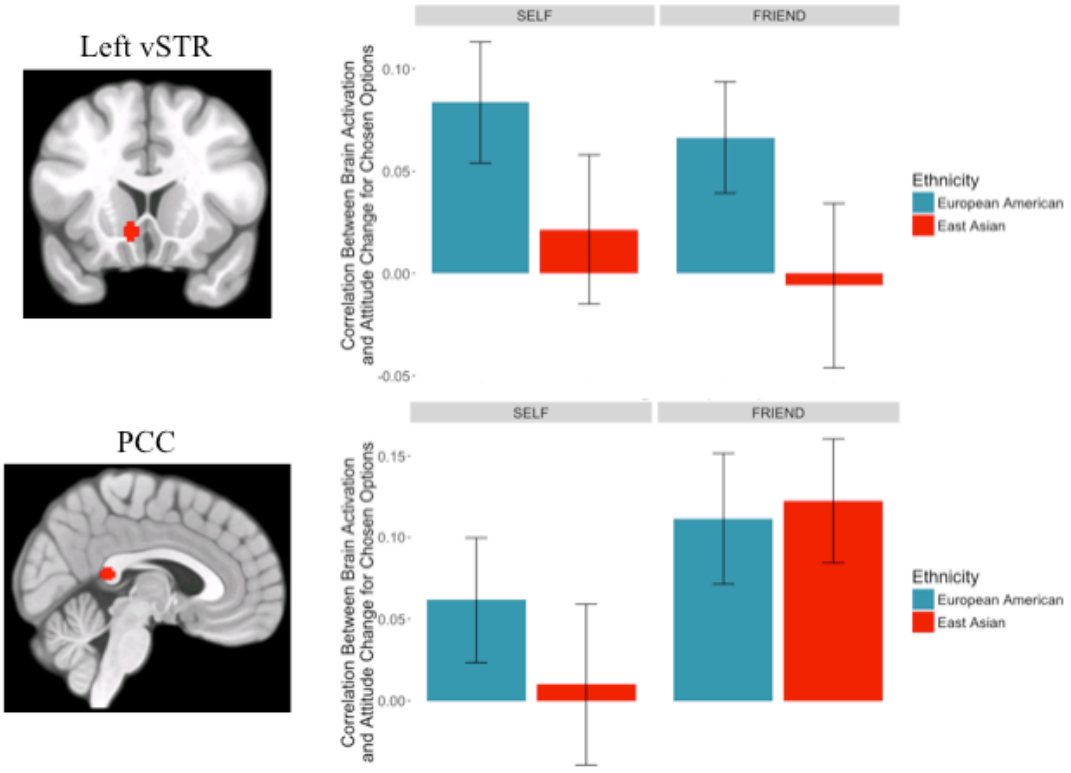


Figure II.4. Brain regions that are recruited significantly more for difficult than easy choices for European Americans and East Asians making choices for the self and a close friend. Results displayed at FDR-corrected p<.05.

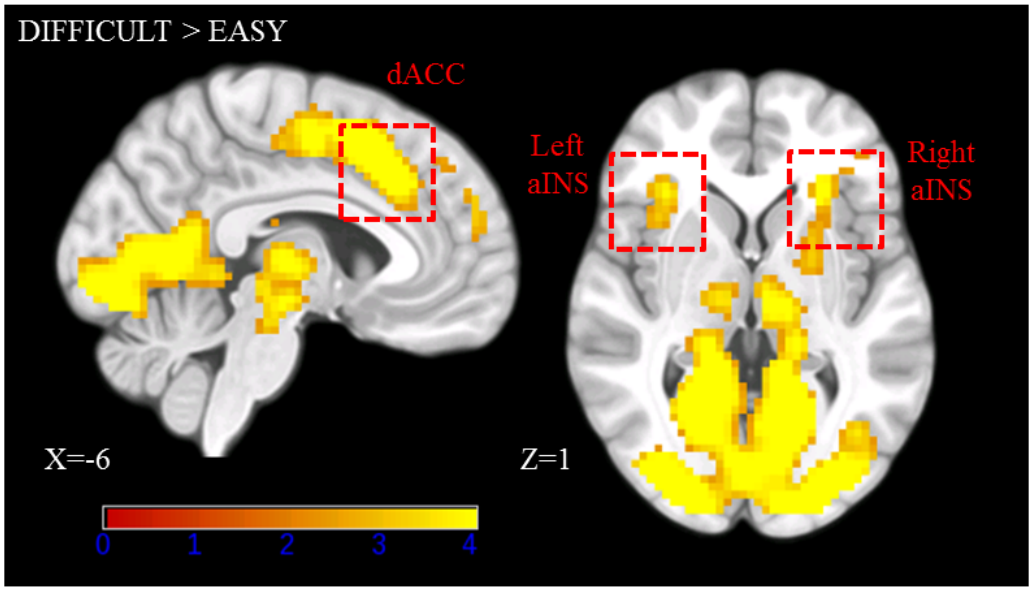


Figure II.5. Functional ROI results from brain regions that were recruited more for difficult than easy choices.

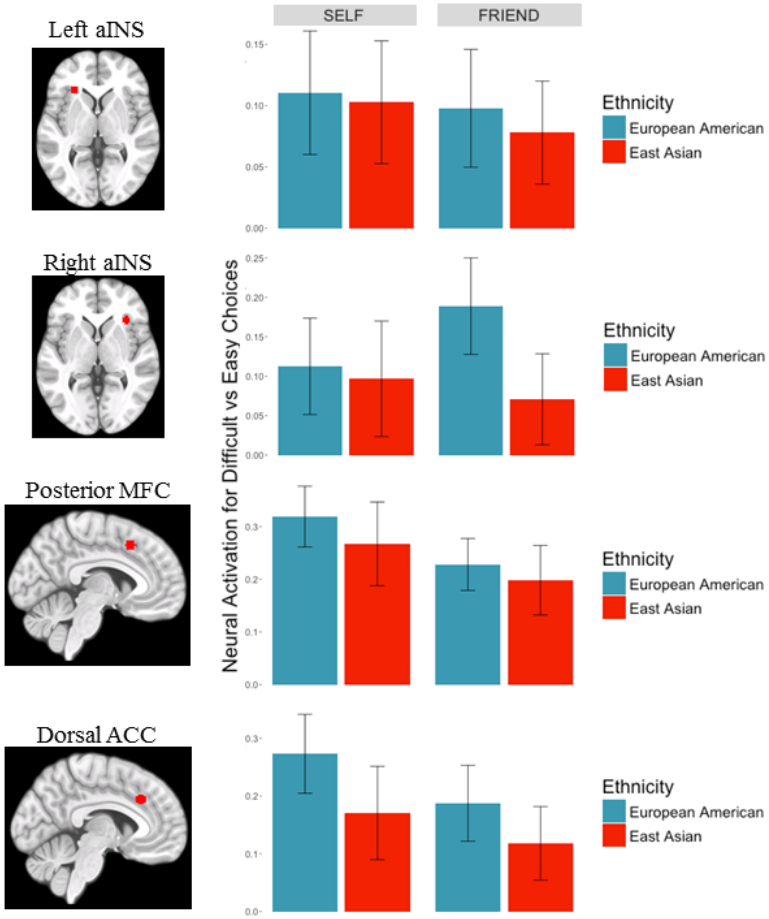


Figure II.6. Brain regions that are recruited significantly more for self than friend choices for European Americans and East Asians. Results displayed at FDR-corrected p<.05.

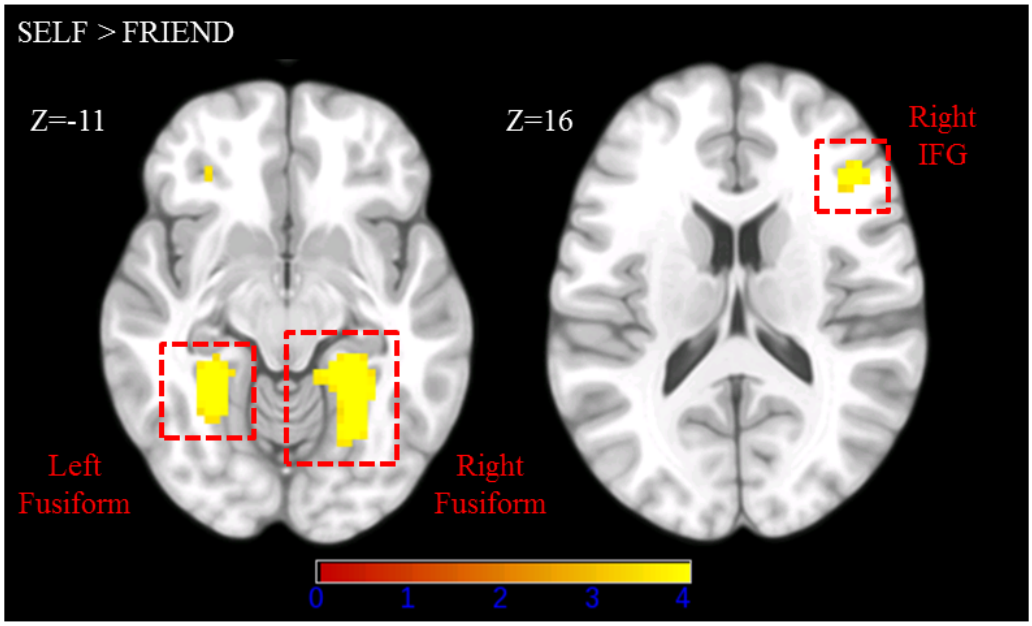


Figure II.7. Functional ROI results from brain regions that were recruited more for self than friend choices.

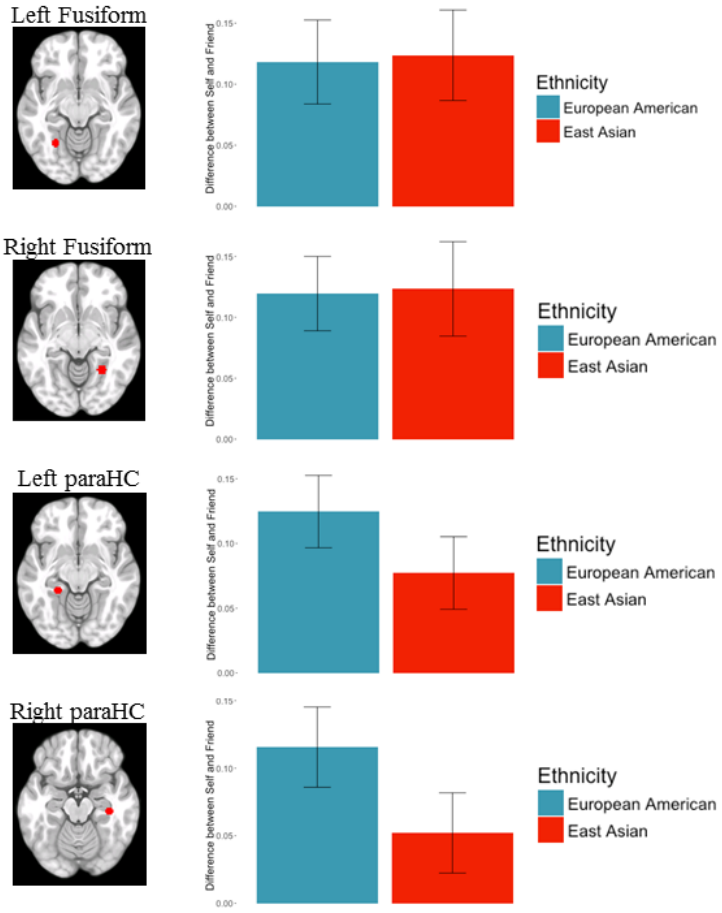


Figure II.8. Brain regions that are recruited significantly more for friend than self choices for European Americans and East Asians. Results displayed at FDR-corrected p<.05.

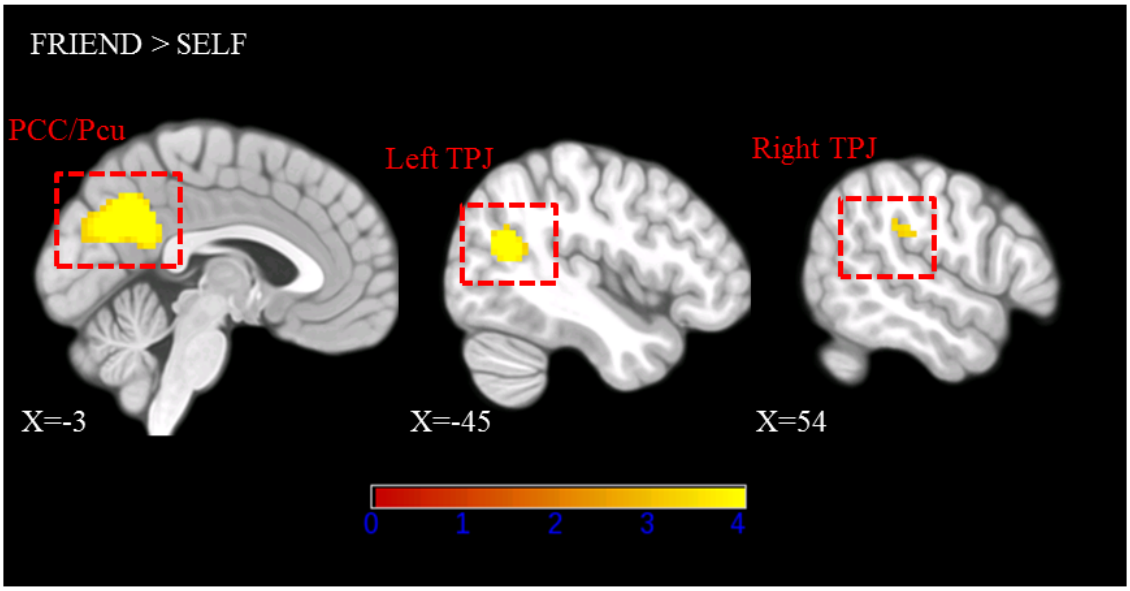
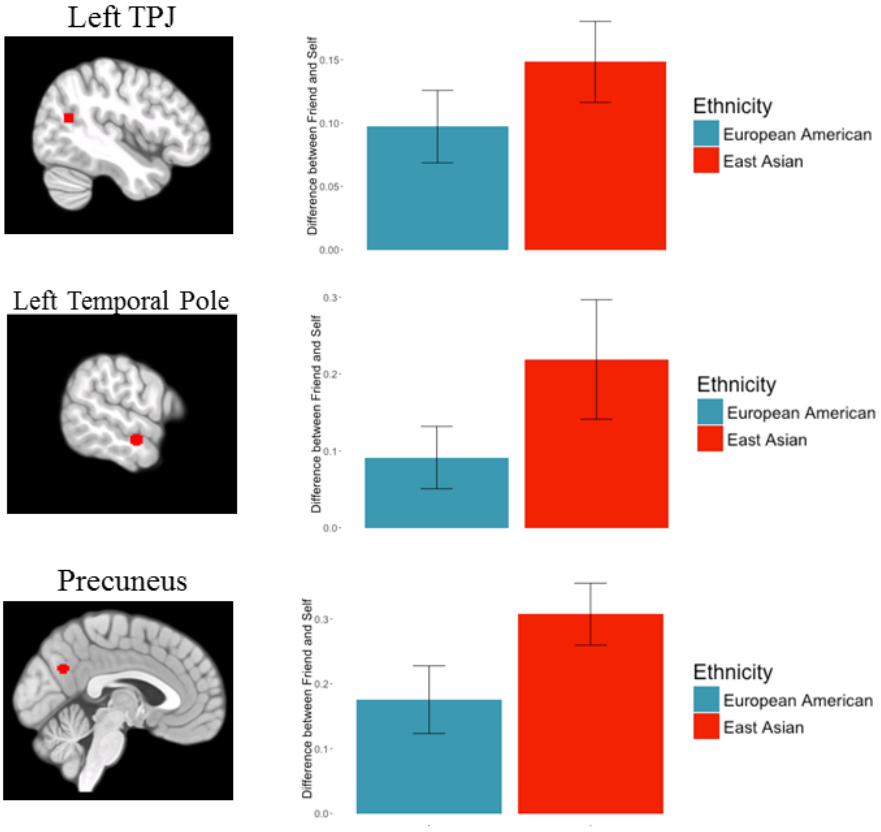


Figure II.9. Functional ROI results from brain regions that were recruited more for friend than self choices.



CHAPTER III

Connectivity between mPFC and PCC predicts post-choice attitude change

Introduction

When people make a choice, they often change their attitudes in a choice-consistent direction (Brehm, 1956; Steele, 1988). Specifically, they will increase their preference for the option they chose and decrease their preference for the option that they rejected. Although this effect of post-choice attitude change is well established and thought to justify the choice, exactly how it might occur is unclear (Chen & Risen, 2010; Eddie Harmon-Jones, Amodio, & Harmon-Jones, 2009; Kitayama & Tompson, 2015; Steele, 1988).

In the current work, I addressed this gap by using functional magnetic resonance imaging (fMRI) to examine the possibility that the decision maker justifies her choice by linking the choice to various aspects of self-knowledge. Although often discussed in social psychological analyses of choice justification (Aronson, 1969; Gawronski et al., 2007; Kitayama et al., 2004; Steele & Liu, 1983), this hypothesis is difficult to test with behavioral measures alone since these measures can only capture down-stream, often distal outcomes of the psychological mechanisms under discussion. By using fMRI, it may be possible to obtain more direct evidence for the self-referential processing hypothesis. Motivated by a recent network-oriented thinking in the field (Poldrack, 2012; Rogers, Morgan, Newton, & Gore, 2007), I hypothesized that the post-choice attitude change should be tracked by the post-choice recruitment of self-relevant knowledge as

indexed by the functional connectivity between putative self-processing areas (i.e., medial prefrontal cortex [mPFC] and posterior cingulate cortex/precuneus [PCC/Pcu]; (Denny et al., 2012; Feyers, Collette, D'Argembeau, Majerus, & Salmon, 2010; Morel et al., 2014; Ries et al., 2012; van der Meer et al., 2010).

Post-Choice Attitude Change

In an attempt to understand the mechanisms underlying post-choice attitude change, it is important to consider a) what might happen during the choice and b) what might subsequently occur once the choice has been made. Researchers using behavioral measures have typically focused on the processes that occur once a choice has been made (post-choice processes), but recent work has begun to unpack how mechanisms during the choice might also contribute to post-choice attitude change (Jarcho et al., 2011; Kitayama et al., 2013). Hence, I discuss the in-choice mechanism first although the primary focus of the current work is in the post-choice mechanism.

In-choice mechanism: search for positive incentives. Kitayama and Tompson (Kitayama et al., 2013; Kitayama & Tompson, 2015) have proposed that when making a choice, the decision maker will look for positive features in one of available choice options. These features would allow her to choose between the options. This hypothesis implies that before a choice is made, the decision maker may develop a new attitude toward one of the options and, moreover, this new attitude may enable her to choose that option. When the attitudes toward the relevant options are assessed at a later time, the chosen option will be liked more than the rejected option. Although this attitude change is assessed after the choice and, thus, is seen as mediated entirely by post-choice mechanisms, it may well take place, at least in part, before the choice has been made.

If the in-choice feature search is instrumental in fostering post-choice attitude change, one may expect that certain brain signals indicating the identification of positive features during the choice will predict a positive shift of the attitude toward the chosen option. Ventral striatum (vSTR) is a subcortical structure thought to track subjective value and reward (Bartra et al., 2013) and has been shown to track changes in subjective value as a function of situational and contextual factors (Varnum, Shi, Chen, Qiu, & Han, 2014) and thus vSTR should be integral in facilitating the in-choice feature search and updating value of the various choice options to foster post-choice attitude change. In support of the in-choice feature search hypothesis, research consistently finds a trial-by-trial change in vSTR reliably tracks post-choice attitude change (Jarcho et al., 2011; Kitayama et al., 2013), suggesting that the decision maker chooses an option if during the choice he/she identifies positive features in it that activate the vSTR.[3]

Post-choice mechanism: recruitment of self-knowledge. Although the in-choice feature search mechanism plays an important role in fostering the post-choice attitude change, it is unlikely that it is the only mechanism involved in this effect. In fact, even after having made a choice, the decision maker may continue to elaborate on information that is relevant to the choice. According to cognitive dissonance theory (Festinger, 1957) and subsequent elaborations of the theory (Aronson, 1969; Gawronski et al., 2007; Steele, 1988), the decision maker may do so in order to justify the choice. Consistent with these theories, I propose that the justification of a choice that has been made is accomplished through active recruitment of an assortment of

[3] Another finding that is consistently obtained in both studies concerns PCC/Pcu. A trial-by-trial change in the in-choice activation of this region also reliably tracked post-choice attitude change. As reviewed later in the paper, PCC/Pcu is often involved in self-referential processing. Hence, the activation of PCC/Pcu could suggest some self-processing was recruited to identify positive features in one of the options. In addition, Jarcho et al. identified several other regions (e.g., mPFC and IFG) as well. However, these regions were not replicated in the Kitayama et al. study.

cognitions that link the chosen option to the self. These cognitions may include: an image of the self as smart and as a good decision maker, autobiographic memories involving the chosen option, and/or future plans with it. These diverse self-referential cognitions will be linked and integrated to justify the choice. For example, the image of the self as a good decision maker might be tied to some memory of having enjoyed using the chosen object in the past and/or certain plans to use it on some special occasions in the future. It is this integrated representation of the chosen option that reinforces the value of the choice and, thus, justifies it.

Our self-referential processing hypothesis of choice justification implies that when a chosen option is presented after the choice, this option will recruit the self-relevant cognitions that were generated during the post-choice processing of choice-relevant information, as well as the brain regions underlying these cognitions. Previous studies have found that the mPFC and PCC/Pcu are linked to self-referential processing (Chua et al., 2011; Denny et al., 2012; Northoff et al., 2006a; van der Meer et al., 2010). I therefore anticipate that these regions will be activated more by the chosen versus the rejected options when they are presented at a later point.

The self-referential processing hypothesis offers another important prediction. The diverse self-cognitions that are recruited during the post-choice processing of the choice (e.g., self-images, episodes remembered, and plans made) are likely to be differentially represented in mPFC and PCC/Pcu. For example, numerous theorists have argued that abstract, trait-like representations of the self are likely to be represented predominantly in the mPFC region, whereas more episodic representations of the self might be relatively more dominant in the relative posterior regions of the brain including PCC/Pcu (P. Qin et al., 2012; Sajonz et al., 2010; van der Meer et al., 2010). Moreover, recent fMRI research has used psychophysiological interaction (PPI) analyses to investigate how task-dependent connectivity between brain regions

is involved in thinking about and evaluating the self. Researchers have found that connectivity between mPFC and PCC/Pcu is greater when people think about and evaluate the self than when thinking about and evaluating others (Feyers et al., 2010; Morel et al., 2014; Ries et al., 2012). mPFC-PCC connectivity is also greater when encoding self-referential information and predicts subsequent recall of self-referential information (Morel et al., 2014). Furthermore, mPFC-PCC/Pcu connectivity is greater when evaluating whether trait words describe the self (self-judgments) than when evaluating whether trait words are positive or negative (valence judgments; Feyers et al., 2010) and the strength of this connectivity is positively correlated with autobiographical memory accuracy (Ries et al., 2012). Thus, connectivity between mPFC and PCC/Pcu is thought to be involved in thinking about and evaluating the self as well as recalling self-relevant memories.

The hypothesis that these self-cognitions are integrated to justify a choice therefore implies that there should be increases in the functional connectivity between mPFC and PCC/Pcu after the choice. Importantly, the self-referential processing hypothesis suggests that this integration of the diverse self-cognitions is instrumental in justifying the choice. As a result, I anticipate that increases in the functional connectivity between mPFC and PCC/Pcu should predict the post-choice (versus pre-choice) attitude toward the chosen option. The same might not apply to the rejected options, insofar as the decision maker is unlikely to devote much effort in linking the rejected options to self-knowledge.

Evidence for the self-referential processing hypothesis is currently scant. In addition to the two fMRI studies reviewed earlier (Jarcho et al., 2011; Kitayama et al., 2013), there are three additional fMRI studies on post-choice attitude change (Izuma et al., 2010; J. Qin et al., 2011; Sharot et al., 2009). These studies focused on neural activations during the pre- and post-choice

rating periods rather than in-choice activations. Given the self-referential processing hypothesis, the activation of mPFC and PCC/Pcu and the functional connectivity between the two regions should predict changes in attitudes towards the choice options. Thus far, only average activation has been tested. In two of the three relevant studies, hypothetical choices were used and, thus, the procedure was not incentive compatible with real values (Izuma et al., 2010; Sharot et al., 2009). It is likely that when the choice is hypothetical, it does not recruit any self-knowledge. It is therefore not surprising that these studies did not find any evidence for the self-referential processing hypothesis. The remaining study (J. Qin et al., 2011) used an incentive compatible procedure where participants received one of the music CDs they chose and found that the activation of both dorsal and ventral regions of the mPFC during the post-choice rating of chosen options predicts the post-choice attitude change for them. Importantly, none of the above studies tested functional connectivity during the pre-choice or post-choice rating tasks and it is therefore unclear whether functional connectivity might be involved in facilitating post-choice attitude change.

Present Research

Guided by the forgoing literature review, the current work tested implications of the self-referential processing hypothesis by using data from the Kitayama et al. (2013) study that had not previously been analyzed. Unlike the Kitayama et al. (2013) study, which focused on in-choice brain activation and tested whether this activation would track subsequent attitude change on a trial-by-trial basis, the current work utilized data on neural activation from both pre-choice and post-choice rating periods and tested between-subjects associations between measures of the recruitment of self-knowledge and post-choice attitude change.

I had three primary predictions. First, for the post-choice (versus pre-choice) rating, the putative self-regions of the brain (mPFC and PCC/Pcu) would be activated relatively more by chosen options as compared to rejected options. Second, the functional connectivity between the two regions during the post-choice (versus pre-choice) rating period should be larger for the chosen options, but no corresponding increases would be expected for the rejected options. Third, increases in the functional connectivity between the two regions for the chosen options at the post-choice (versus pre-choice) rating should predict post-choice (versus pre-choice) attitude toward the chosen but not rejected options in choice-consistent directions.

Our secondary goal was to explore individual differences in the degree to which self-processing increases from pre-choice to post-choice. Previous evidence suggests that individuals with independent self-construal are more likely to consider personal choices to be relevant to the self (Na & Kitayama, 2012; Savani et al., 2008, 2010). Extending recent work in cultural neuroscience (Han et al., 2012; Hyde, Tompson, Creswell, & Falk, 2015) that has found that culture and self-construal influence how the brain makes social and cognitive judgments (Gutchess, Welsh, Boduroglu, & Park, 2006; Ma et al., 2012; Park, Tsai, Chim, Blevins, & Knutson, 2016; Varnum et al., 2014), I investigated whether the neural activation of putative self-regions (i.e., mPFC and PCC/Pcu), as well as the connectivity between them, during the post-choice (versus pre-choice) rating period might increase as a function of independent self-construal.

Method

Participants

Twenty-five undergraduates at the University of Michigan participated in the study. One participant was excluded from analysis due to excessive head movement. Analysis was

performed on the remaining 24 participants (10 males and 14 females, mean age = 19.71, SD = 1.43). All participants were born and raised in the United States, had normal or corrected-to-normal vision and had no history of head injury or psychiatric illness. Participants received $50. At the end of the study, they were offered the option of either keeping one of the CDs they chose or receiving eight more dollars instead of the CD. All participants opted for the extra cash. All participants gave written consent and the Institutional Review Board at the University of Michigan approved the procedure.

Procedure and Materials

Following the procedure from previous behavioral studies on choice (e.g., Kitayama et al., 2004), I used popular music CDs as stimuli. I sampled 160 CDs from the Billboard Top 100 music CDs and the Apple iTunes Top 100 music CDs from September 2009 to November 2009 and conducted the study during the first half of 2010.

Approximately 1.5 weeks prior to the experiment, participants filled out a survey packet that included the Singelis self-construal scale (Singelis, 1994). Upon arrival at the fMRI center, participants performed three tasks inside the scanner. First, they completed two runs of a pre-choice rating task. They were shown the covers for 120 popular music CDs one at a time in randomized order (60 CDs in each run), and asked to rate how much they liked each CD on a 5-point scale (1=least likeable, 5=most likeable). The cover of each CD was displayed for 3 seconds along with the artist and album title, with an average inter-stimulus interval of 4 seconds (2, 4 or 6s, jittered). The second fMRI task involved a single run of the choice task. Participants were presented with 60 pairs of CD covers (30 easy pairs and 30 difficult pairs as determined by how similar or different they rated the items during the pre-choice rating task). Participants selected the CD they wanted in each pair. It was explained that one of the 60 CDs chosen by the

participant would be randomly selected and given to the participant at the end of the session; so the choices were incentive compatible with real values. Third, participants repeated two runs of the rating task described above. This study focuses on brain activation patterns during the pre-choice and post-choice rating tasks.

Singelis Scale

I used an abbreviated 20-item version of the Singelis self-construal scale (Singelis, 1994) to assess independent and interdependent self-construal (See Appendix for specific items used). This version of the scale consists of two subscales (10 items each). Independent self-construal was assessed by averaging each participant's responses to 10 items pertaining to one's uniqueness and autonomy (e.g., "I enjoy being unique and different from others in many respects"), whereas interdependent self-construal was assessed by averaging each participant's response to 10 items concerning one's interpersonal relatedness and values placed on social harmony (e.g., "I will sacrifice my self-interest for the benefit of the group I am in"). Participants rated how much each item described the self on a 5-point scale (1=doesn't describe me at all, 5=describes me very much). The reliabilities were comparable to those obtained in previous work (Cronbach's αs =.76 and .59, for independence and interdependence, respectively).

Participants reported slightly higher independent self-construal (M=3.74, SD=0.55) than interdependent self-construal (M=3.56, SD=0.47), although this difference was not statistically significant ($t(23)=1.01$, $p=.323$). There was a significant negative correlation between independent and interdependent self-construal ($r=-.46$, $p=.025$), such that individuals who reported higher independent self-construal were also more likely to report lower interdependent self-construal.

fMRI Data Acquisition

Participants were tested in a GE 3T Signa Excite 2 scanner (Milwaukee, Wisconsin). I first acquired a standard T1 structural image for alignment (TR = 250, TE = 3.7, FA = 75, FOV = 220, 43 oblique axial slices, matrix 256 x 256, slice thickness = 3.5, 0 skip). During the experimental task, T2*-weighted, spiral-in acquisition sequence were acquired (gradient echo, TR = 2000, TE = 30, FA = 90, FOV = 220, 43 oblique axial slices, matrix 64 x 64, slice thickness 3.0 mm, 0 skip). Four initial volumes were discarded at the beginning of each run to allow for stabilization of the MRI signal. Finally, a high-resolution T1 anatomical scan was obtained (three-dimensional spoiled-gradient echo [SPGR] with inversion recovery prep, time of inversion = 400 ms, TR = 9.0, TE = 1.8, FA = 15, FOV = 260, 128 slices, matrix 256 x 256, 1.2 mm slice, 0 skip).

fMRI Data Analysis

Data were analyzed using the statistical parametric mapping software package, SPM8 (Welcome Department of Cognitive Neurology, London, UK). Functional volumes were slice time corrected using MCFLIRT (Jenkinson, Bannister, Brady, & Smith, 2002) to account for temporal differences in slice acquisition time, realigned to correct for head motion, and spatially normalized to a standard template based upon the Montreal Neurological Institute (MNI) reference brain using VBM8 toolbox and DARTEL high dimensional warping, and spatially smoothed using a 5-mm Gaussian kernel.

Data for the pre-choice and post-choice rating tasks were modeled using an event-related design and a modified general linear model (Worsley et al., 1992, 1997). First-level models included a boxcar function for each 3-second trial, with separate regressors for time (pre-choice vs. post-choice), choice (chosen vs. rejected), and difficulty (difficulty vs. easy, defined by the

pre-choice difference in preference ratings for the CDs in each pair).[4] Movement parameters were included as covariates for all models.

I used a large-scale study on self-referential processing (Chua et al., 2011) to define a set of a priori functional ROIs in mPFC and PCC/Pcu. Using SPM8 and MarsBaR, I created 10mm sphere ROIs around the peak voxels in the mPFC (3,60,12) and PCC/Pcu (-3,-51,33) regions that have been linked to thinking about and evaluating the self (relative to a valence judgment; FWE-corrected, $p<.05$, cluster threshold of $k>50$; see Figure III.1). All coordinates are reported in MNI space. I ran two sets of analyses using our a priori mPFC and PCC/Pcu ROIs focusing on (i) the activations of the mPFC and PCC/Pcu ROIs and (ii) the functional connectivity between the two ROIs.

Activation of the mPFC and PCC/Pcu ROIs. A series of three analyses were performed. (i) The average activation of each ROI was analyzed in a 2 (Choice) x 2 (Time) repeated-measures ANOVA. Follow-up simple effects analyses were performed with two-tailed t-tests, with significance threshold set to 0.05. (ii) I used multiple linear regression analyses to test whether the mPFC and PCC/Pcu activations during the post-choice (versus in-choice) rating period of chosen options would predict the post-choice attitude change for these options. This same analysis was repeated for rejected options. (iii) Further, I used linear regression analysis to explore whether independent or interdependent self-construals would predict the mPFC and PCC/Pcu activations during the post-choice (versus pre-choice) rating of chosen options. I repeated the same analysis for the rejected options.

Functional connectivity between mPFC and PCC/Pcu. In order to examine the

[4] No main effects or interactions were observed for Difficulty and so subsequent analyses focused on the effects of Choice and Time.

functional connectivity between mPFC and PCC/Pcu, I used a generalized psycho-physiological interaction (gPPI) analysis with the mPFC ROI as the seed (McLaren, Ries, Xu, & Johnson, 2012). Similar to standard PPI (sPPI), gPPI identifies an association between the time courses of activation for two regions first and then tests whether the magnitude of this association will vary as a function of a psychological variable(s). If the association between the two regions should vary as a function of this psychological variable(s), this psycho-physiological interaction (PPI) would constitute evidence for the functional connectivity between the two regions. Unlike sPPI, gPPI identifies the strength of this association in each condition separately (i.e., identifies a separate regressor for each condition and the interaction between the time course for each condition and the time course of the neural activation). This allows researchers more flexibility to run multiple contrasts to test whether this relationship differs for one condition versus another (or versus multiple other conditions), especially when there are more than two conditions (McLaren et al., 2012).

I used the same set of analyses that were used to examine average activation within mPFC and PCC/Pcu to examine the functional connectivity between mPFC and PCC/Pcu. For every voxel outside of the mPFC ROI, I first computed the task-related association between each voxel and the mPFC ROI (i.e., computed the PPI regressor). This was done separately for each of the four conditions defined by Time (pre- versus post-choice) and Choice (chosen versus rejected). I then extracted the average beta value in the PCC/Pcu ROI in each of the four conditions to get a measure of the task-related association between mPFC and PCC/Pcu in each condition.

(i) The average beta values for mPFC-PCC/Pcu functional connectivity were submitted to a 2 (Choice) x 2 (Time) repeated-measures ANOVA. Follow-up simple effects analyses were

performed with two-tailed t-tests, with significance threshold set to 0.05. (ii) For the chosen options, I tested whether increases in the functional connectivity between mPFC and PCC/Pcu during the post-choice (versus pre-choice) rating period would predict post-choice attitude change in a regression analysis. I ran the same set of analyses for rejected options. (iii) Further, I explored whether independent or interdependent self-construals would predict the changes in the functional connectivity between mPFC and PCC/Pcu during the post-choice (versus pre-choice) rating of the chosen options. I repeated the same analysis for the rejected options.

Results

Behavioral Results

I first analyzed preference ratings of the options. I found a significant 2-way interaction between choice (chosen vs. rejected) and time (pre-choice vs. post-choice; $F(1,23) = 8.26$, $p = .009$). Preference for chosen options increased from pre-choice ($M=3.16$, $SD=0.37$) to post-choice ($M=3.25$, $SD=0.41$; $t(23)=7.01$, $p<.001$), whereas preference for rejected options decreased from pre-choice ($M=2.13$, $SD=0.38$) to post-choice ($M=2.03$, $SD=0.34$; $t(23)=-4.15$, $p<.001$). There was no correlation between the behavioral ratings and either independent self-construal or interdependent self-construal.

fMRI Results

mPFC and PCC/Pcu activations. The mPFC activations in the relevant conditions are shown in Figure III.1-A. The Choice x Time interaction was significant ($F(1,23)=5.32$, $p=.030$). Subsequent simple effect tests showed that the activation was no different between the chosen and the rejected options at the pre-choice rating period ($t(23)=-0.45$, $p=.657$), but it was significantly greater for the chosen options than for the rejected options during the post-choice rating ($t(23)=3.07$, $p=.005$). The pattern for the PCC/Pcu activation, shown in Figure III.1-B,

also showed a significant interaction between Choice and Time ($F(1,23)=6.74$, $p=.016$). The PCC/Pcu activation was no different between the chosen and the rejected options at the pre-choice rating ($t(23)=0.96$, $p=.349$), but it was significantly greater for the chosen options than for the rejected options during the post-choice rating period ($t(23)=4.21$, $p<.001$).

Subsequent regression analyses showed that the changes in the activation of mPFC and PCC/Pcu did not predict post-choice attitude change. The mPFC activation during the post-choice (versus pre-choice) rating of the chosen options had no effect on the post-choice (versus pre-choice) attitude for the chosen options ($\beta=-.33$, $p=.13$). It also had no effect on the post-choice (versus pre-choice) attitude for the rejected options ($\beta=-.10$, $p=.654$). The PCC/Pcu activation during the post-choice (versus pre-choice) rating of the chosen options had no effect on the post-choice (versus pre-choice) attitude of these options ($\beta=-.01$, $p=.987$). It also had no effect on the post-choice (versus pre-choice) attitude for the rejected options ($\beta= -.08$, $p=.701$, respectively).

Further regression analyses tested the effects of independent and interdependent self-construals. I found that increases in independent self-construal predicted increased activations in mPFC ($\beta=.50$, $p=.012$) and PCC/Pcu ($\beta=.47$, $p=.020$) from pre-choice to post-choice for chosen options. There was no effect of independent self-construal on neural activation for rejected options, nor was there a relationship between interdependent self-construal and neural activation for chosen or rejected options[5].

[5] In addition, I tested whether brain activation for any of the analyses above would be moderated by choice difficulty. There were no significant differences between difficult and easy choices for any of the analyses noted above.

Functional connectivity between mPFC and PCC/Pcu. When the task-related association between the two putative self-regions (mPFC and PCC/Pcu) was analyzed as a function of Choice and Time, the interaction between these two factors did not achieve statistical significance ($F(23)=1.88$, $p=.184$). Nevertheless, this association did increase, albeit marginally, during the post-choice (versus pre-choice) rating of the chosen options ($t(23)=1.77$, $p=.091$). In contrast, there was no change from pre-choice to post-choice in the functional connectivity between the two regions during the rating of the rejected options ($t(23)=0.55$, $p=.587$; see Figure III.2-A). This pattern suggests a slight increase of the functional connectivity between the two regions during the rating of the chosen options.

Subsequent regression analyses tested whether increases in the functional connectivity between the two regions during the post-choice (versus pre-choice) rating of the chosen options would predict the post-choice (versus pre-choice) attitudes toward these options. As shown in Figure III.2-B, I found that the increases in this association significantly predicted the attitude change for the chosen options ($\beta=.43$, $p=.035$). This is consistent with the hypothesis that increased functional connectivity between the two putative self-regions in the processing of the chosen options reinforces the positive attitude toward them. There was no comparable effect for the rejected options ($\beta=.01$, $p=.956$).

Further regression analyses tested the effects of independent and interdependent self-construals on the functional connectivity between the two putative self-regions (mPFC and PCC/Pcu). There was no effect of either independent self-construal or interdependent self-construal on this association at the post-choice (versus pre-choice) rating for the chosen options ($\beta=.02$, $p=.934$; $\beta=-.20$, $p=.344$; respectively). Nor did I find any effect of either independent

self-construal or interdependent self-construal on this association at the post-choice (versus pre-choice) rating of the rejected options (β=.07, p=.735; β=.-.03, p=.904; respectively).

Discussion

The Self-Referential Processing Hypothesis of Post-Choice Attitude Change

The self-referential processing hypothesis of post-choice attitude change holds that after making a choice, individuals link the choice to their self-knowledge so as to justify it. The hypothesis is consistent with the existing social psychological theories of post-choice attitude change (Aronson, 1969; Kitayama & Tompson, 2015; Steele, 1988; Stone & Cooper, 2001). Moreover, it offers clear predictions about the brain mechanisms that are likely to be recruited to produce choice justification. The current work provided the first neural evidence that lends support to some critical implications of this hypothesis.

First, I observed that during the post-choice (versus pre-choice) rating of the chosen (versus rejected) options there was an increased activation in both mPFC and PCC/Pcu (the two primary regions putatively linked to self-referential processing). Second, there was a marginal increase in the connectivity between the two regions during the post-choice (versus pre-choice) rating of the chosen options. No comparable effect was evident for the rejected options. Third and most importantly, the increased functional connectivity between mPFC and PCC/Pcu during the post-choice (versus pre-choice) rating of the chosen options reliably predicted the post-choice attitude change of the chosen options. There was no effect of the functional connectivity for the rejected options. Nor was there any effect of the activation of either mPFC or PCC/Pcu assessed separately on post-choice attitude change. While mPFC and PCC/Pcu separately are involved in multiple diverse cognitive processes, the only cognitive processes that mPFC activation, PCC/Pcu activation, and connectivity between mPFC and PCC/Pcu have all been implicated in

are thinking about and evaluating the self and recalling memories about the self (Feyers et al., 2010; Morel et al., 2014; Ries et al., 2012; van der Meer et al., 2010). Taken together, the evidence is consistent with the hypothesis that self-referential processing after the choice is associated with attitude change.

One additional finding is potentially important. I assessed independent and interdependent self-construal and found that independent self-construal reliably predicted changes in neural activation within mPFC and PCC/Pcu for chosen options. This finding lends some tentative support to the prediction that individuals who view the self as independent from others take their choices more seriously and thus expend more effort to justify them. In the current study, however, the increased activation of mPFC and PCC/Pcu was not related either to greater connectivity between mPFC and PCC/Pcu or to post-choice attitude change. Thus, I found no evidence that independent self-construal is linked to a greater likelihood of choice justification.

Altogether, our work goes beyond previous work that has examined post-choice mechanisms of choice justification (Izuma et al., 2010; J. Qin et al., 2011; Sharot et al., 2009). Unlike Izuma et al. (2010) and Sharot et al. (2009), I used an incentive compatible procedure where participants received one of the options they chose. This could explain why neither Izuma et al. nor Sharot et al. found any evidence for the self-referential processing hypothesis, but I did. Unlike Qin et al. (2011), I used a region of interest analysis, which enabled us to disambiguate the functional significance of our brain activation data. Most importantly, none of the previous studies examined post-choice functional connectivity, and our study was the first to test whether functional connectivity predicts post-choice attitude change. This work therefore expands upon

previous work by showing that networks of brain regions are important in promoting and facilitating post-choice attitude change.

Interestingly, our data suggest that the functional connectivity between mPFC and PCC/Pcu is empirically distinct from the activation of each of the two regions assessed separately. Moreover, it is the functional connectivity rather than the separate activation of each region that is linked to attitude change. While activation in separate regions can provide insight into the cognitive processes that each region supports, ultimately this activation reflects communication between brain regions, and thus connectivity provides unique insight into how these brain regions contribute to attitude change. Thus, connectivity may in fact be a more proximal measure of how the brain is processing information. This more dynamic facet of brain network must be further capitalized on in future work to advance our understanding of the neural mechanisms underlying how people think about the self.

Integrating the In-choice and Post-choice Mechanisms

Post-choice attitude change is likely to be mediated by both in-choice mechanisms and post-choice mechanisms. Our earlier work tested in-choice mechanisms including a search of positive features in one choice option (Kitayama et al., 2013), whereas the current work tested post-choice mechanisms including self-referential processing. Although the two mechanisms are conceptually distinct, they might in fact be interconnected and the entire process might be far more recursive than our discussion so far might imply (Kitayama & Tompson, 2015).

For example, when two equally attractive options are presented for a choice, the decision maker is likely to seek positive features that are uniquely linked to one of the options. These features are unlikely to be purely perceptual. To the contrary, more often than not, substantial cognitive processing including retrieval of prior episodes and future plans may be required to

recognize certain features as positive. Hence, it is likely that certain degrees of self-referential processing are involved during the in-choice processing. Consistent with this line of analysis, prior evidence suggests that in-choice activation of PCC/Pcu (a region closely linked to self-referential processing) tracks post-choice attitude change (Jarcho et al., 2011; Kitayama et al., 2013; see Footnote 1). Hence, higher-order self-referential cognitions may be already implicated very early on during the choice processes.

Moreover, once one of the options has been chosen, individuals may be expected to expend further self-referential processing to justify the choice. Yet, it is conceivable that this self-referential processing reinforces the affective value of the chosen option as represented in the subcortical reward processing regions of the brain including vSTR (Kitayama & Tompson, 2015). Hence, it is plausible that at least under certain conditions, post-choice activation of vSTR tracks post-choice attitude change. Evidence for this prediction exists in the literature (Izuma et al., 2010; Sharot et al., 2009) although I did not find any evidence for it in an additional exploratory whole-brain analysis.

At present, there are no analytic tools at hand to analyze the feedback / feed-forward links between the in-choice and the post-choice mechanisms discussed above. Future work would nonetheless benefit from a more concerted analysis of this issue.

Is Post-Choice Attitude Change No More Than A Statistical Artifact?

By using neuroimaging to examine underlying mechanisms, our work addressed a recent criticism that post-choice attitude change is no more than a statistical artifact. Chen & Risen (2010) have argued that measurement error obscures differences in true preferences for the two choice options. They argue that even when two choice options are initially rated as equally preferred, it is likely that the individual's true preference for one option is actually greater than

the other. This has two consequences. First, the individual will choose the option that is actually more preferred (according to the individual's true preferences) even though the initial ratings suggested that they were equally preferred. Second, because the true preference for the chosen option was actually greater than the true preference for the rejected option, the second, post-choice rating of the chosen option is likely to increase, whereas the second post-choice rating of the rejected option is likely to decrease. Following this line of reasoning, Chen and Risen have argued that the measurement errors associated with the initial preference rating might be solely responsible for the post-choice attitude change and thus psychological processes (e.g., cognitive dissonance, self-referential processing, etc.) are not required for this attitude change to occur.

Although certain mathematical details involved in the original analysis have since been called into question (Alós-Ferrer & Shi, 2015), the statistical artifact implied by the Chen & Risen (2010) argument stands as a logical possibility that could increase post-choice attitude change. However, because measurement of attitude change and measurement of neural activation are independent, the artifact described by Chen and Risen is unlikely to lead to any systematic changes in the activation in any brain regions, connectivity among them, or the association between these brain signals and attitude change (Kitayama, Tompson, & Chua, 2014). If post-choice attitude change is predicted by neural activation, then I can conclude that some meaningful percentage of this attitude change is independent of the statistical artifact described by Chen and Risen. Hence, our findings underscore the veracity of post-choice attitude change as a psychological phenomenon.

Conclusion

The most important contribution of the current work is to show that connectivity between brain regions during post-choice evaluation of the choice options contributes to attitude change.

These findings extend previous research that hypothesized self-referential processing to account for post-choice attitude change without directly assessing this processing (Aronson, 1969; Gawronski et al., 2007; Steele, 1988; Stone & Cooper, 2001). In addition to contributing to the current understanding of brain mechanisms underlying choice justification, our findings also underscore the potential of a network-based analysis focusing on functional connectivity in testing social psychological theories.

Figure III.1. Activation in medial prefrontal cortex and posterior cingulate cortex changes from pre-choice to post-choice.

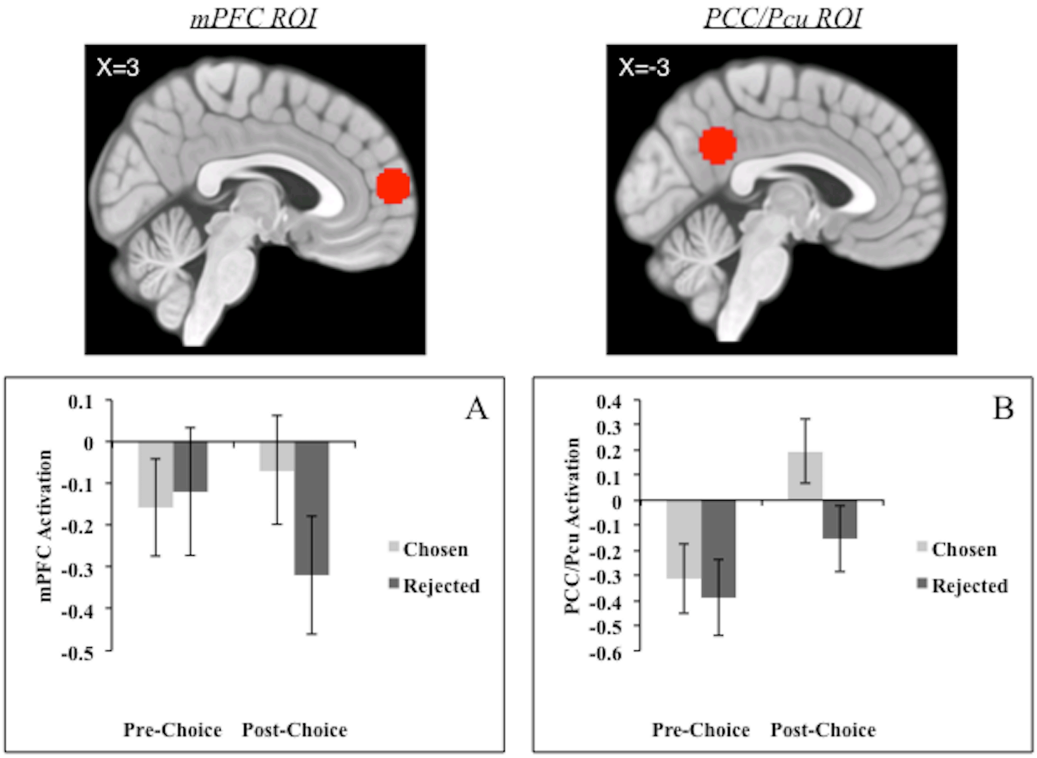
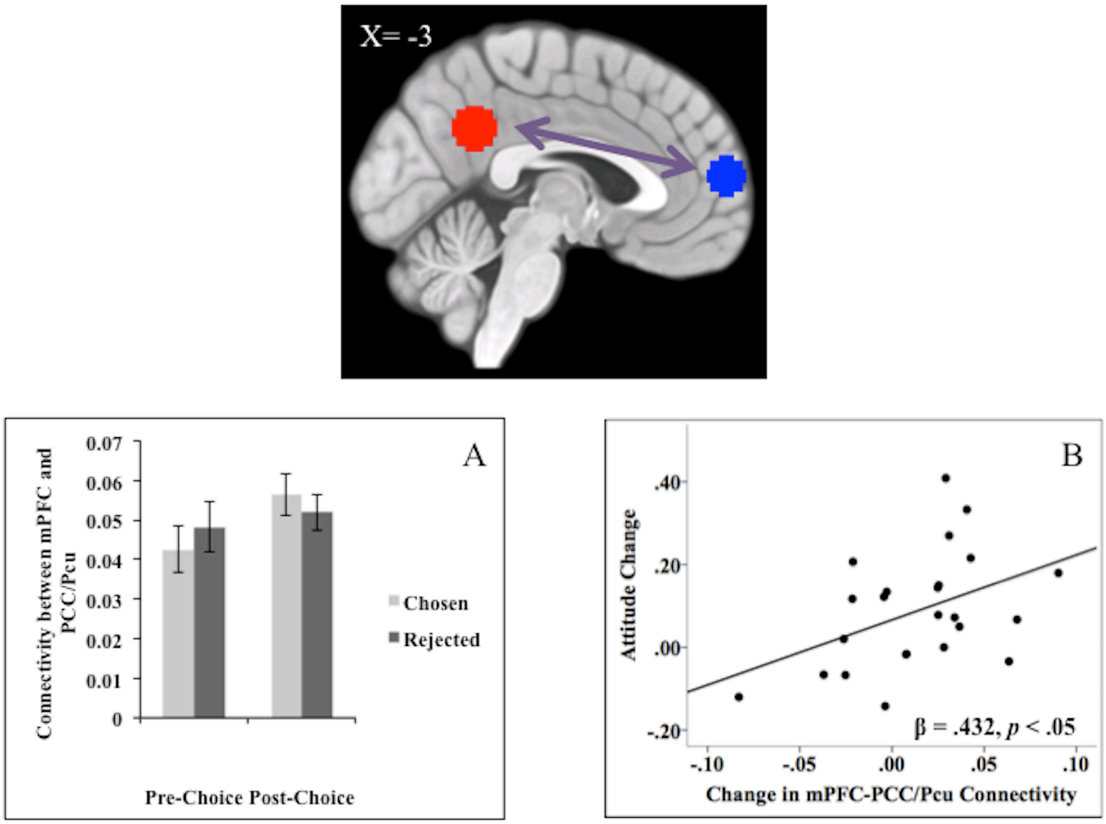


Figure III.2. Changes in connectivity between medial prefrontal cortex and posterior cingulate cortex predict attitude change.



CHAPTER IV

Multivariate Representations of Choice Information

Introduction

People are constantly bombarded with choices in their everyday lives. These choices may often be quite difficult, involving complex information about the choice options. How do people process information about these choice options? And are the brain regions involved in representing choice information influenced by the cultural background of the chooser?

While there are many brain regions that have been identified as being involved in choice, research has typically focused on average levels of activation within a single brain region. This approach can yield valuable information about whether a brain region as a whole is involved in decision-making, but it does not consider patterns of activation within that brain region. Multivariate patterns of activation within a brain region can provide valuable knowledge about how information is actually represented in a particular brain region (Mur et al., 2009). Recent work has begun to use multivariate pattern analysis to unpack how these brain regions are involved in processing and representing information about the choice (Carter et al., 2012; Garvert, Moutoussis, Kurth-Nelson, Behrens, & Dolan, 2015; Kahnt, Heinzle, Park, & Haynes, 2011). However, none of these studies have examined whether these multivariate neural representations differ across cultures, nor have they considered choices made for others. The current work uses representational similarity analysis (RSA; Kriegeskorte, Mur, & Bandettini, 2008; Nili et al., 2014) to examine how patterns of activation within regions previously

identified as being involved in choice might also be involved in representing choice information. Moreover, this research is the first to directly test how people from difficult cultural backgrounds represent choice information in the brain.

Multivariate representations of choice information

I test these questions using RSA to measure the representational structure of choice information in the brains of people who are evaluating choice options. RSA examines how the patterns of activation within a specific brain region fluctuate from trial to trial and how fluctuation in the patterns of activation correlates or fits with explicit models of choice information. This allows me to examine whether the multivariate pattern of activation within a specific brain region is correlated with the choice information on each trial. For example, to the extent that the model for choice outcome (chosen vs. rejected) is correlated with the neural representation in medial prefrontal cortex (mPFC), I could then conclude that choice is represented in mPFC. And if the model for choice target (self vs. friend) is correlated with the neural representation in temporoparietal junction (TPJ), I could then conclude that choice target is represented in TPJ. Additionally, I can examine whether culture influences the strength of the representation of choice information (measured by the strength of the correlation between the model of choice information and the multivariate pattern of activation within a specific brain region). In the current study, I focus on neural representations of 1) whether the choice option was chosen or rejected (choice outcome), and 2) whether the choice was made for the self or a close friend (choice target).

Previous work on brain regions involved in choice

As described in more detail in Chapters 2 and 3, there are a number of brain regions that have been identified as being involved in decision-making and evaluating choice options. mPFC

and ventral striatum (vSTR) process subjective value of choice options, both when evaluating one's own preferences and when thinking about another person's preferences (Bartra et al., 2013; Janowski et al., 2013; Zaki et al., 2014). mPFC and posterior cingulate cortex (PCC) are also recruited more when evaluating chosen options (versus rejected options; Chapter 3). Additionally, multivariate patterns in mPFC, PCC, and vSTR track subjective reward and represent information about upcoming choices (Carter et al., 2012; Garvert et al., 2015; Kahnt et al., 2011).

In addition to brain regions that are recruited similarly for choices made for the self and friend, other brain regions are recruited differentially when evaluating choice options for the self or friend. For instance, regions involved in mentalizing (e.g., dorsal mPFC [dmPFC] and TPJ) are more strongly recruited when making a choice whether to gamble for a partner than when making a choice whether to gamble with one's own money (Jung et al., 2013). Additionally, in Chapter 2, regions involved in mentalizing (e.g., TPJ) are recruited more when people make consumer choices for a close friend (versus make consumer choices for the self). Carter and colleagues (2012) argue that multivariate patterns in TPJ are involved in integrating social information about another's intentions into a choice.

Furthermore, very few studies have examined how activation of these brain regions change over time, and thus an additional question is whether these representations might change from pre-choice to post-choice. In the current study, I chose to focus on neural activation during the pre-choice and post-choice rating tasks—that is, while participants evaluated choice options individually either before or after they made their choice. The benefit of this analysis is that it allows me to examine individual features of each choice option, rather than examining brain activation while individuals process multiple choice options at the same time. Additionally, by

examining neural representations at two time points, I can test whether representations of choice information change from pre-choice to post-choice. If brain regions represent information about choice outcome during the pre-choice rating task, then multivariate representations in these regions could actually be driving the subsequent choice. But, if differentiation of the patterns of activation for chosen and rejected options only occurs after the choice, then it suggests that these brain regions are representing the outcome of the choice.

However, virtually all of the studies mentioned above tested participants from Western, individualistic cultures and it is thus unclear whether the same brain regions are involved in representing choice information for people from non-Western cultures. While it is clear that cortical regions including mPFC, PCC, and TPJ as well as subcortical regions including vSTR facilitate decision-making and represent choice information, it isn't clear whether culture influences these neural representations.

Culture and Choice

For people from individualistic cultures, choice is seen as an opportunity to express the self, such as when individuals buy cars that fit their tastes, attend a college that suits them, or select a mate that attracts them (Kim & Sherman, 2007). However, Markus and Kitayama (2003) argue that, unlike Western views of choice and independence, East Asian culture emphasizes that "actions are responsive to obligations and expectations of others, roles, and situations; preferences, goals, and intentions are interpersonally anchored" (p. 7). If culture influences how people think about and evaluate choice, then there might be also be cultural differences in how people process and represent choice information.

In fact, there is some evidence that many of the brain regions involved in choice are activated differentially for people from individualistic and collectivistic cultures. A recent meta-

analysis found that, across a variety of social judgments (such as inferring the mental states of others or thinking about the self), people from collectivistic cultures such as Japan (who view the self as interdependent and fundamentally intertwined with others; Markus & Kitayama, 1991) are more likely to recruit mentalizing brain regions such as dorsal medial prefrontal cortex (dmPFC) and TPJ (Han & Ma, 2014). By contrast, people from individualistic cultures such as the United States (who view the self as independent, autonomous, and distinct from others; Markus & Kitayama, 1991) are more likely to recruit brain regions involved in thinking about and evaluating the self such as ventral medial prefrontal cortex (vmPFC; Han & Ma, 2014). In Chapter 2, I also find that mentalizing regions appear to be recruited more for East Asians making friend choices.

Present Research

The first goal of the current work was to identify which brain regions are involved in representing information about the choice options. I hypothesized that regions involved in thinking about and evaluating the self and evaluating/encoding subjective value should be involved in representing the choice outcome (chosen versus rejected options). Moreover, regions involved in thinking about the self, as well as thinking about the mental states of others should be involved in representing the target of the choice (self versus friend). The second goal was to test whether culture might moderate these representations. I hypothesize that self-processing regions should be more strongly involved in representing choice information for European Americans, whereas mentalizing regions should be more strongly involved in representing choice information for East Asians. The third goal was to test whether representation of choice outcome or choice target might change from pre-choice to post-choice. In order to test these hypotheses, I

used RSA to test multivariate patterns of activation during the pre-choice and post-choice rating tasks.

Method

Participants

One hundred nine undergraduates at the University of Michigan participated in the experiment[6]. Twenty-six participants were excluded due to data quality issues (fourteen due to excessive head motion, four due to missing responses to greater than 25% of trials, four due to brain artifacts, and four due to scanner issues). Analysis was performed on the remaining 83 participants (45 European Americans [29 females and 16 males], 38 East Asians [25 females and 13 males]). All participants had normal or corrected-to-normal vision and had no history of head injury or psychiatric illness. Participants received $60 as well as one of the posters they chose for themselves and one of the posters they chose for their friend (to give as a gift to their friend). All participants gave written consent and the Institutional Review Board at the University of Michigan approved the procedure.

Stimuli

Participants were presented with images of posters taken from AllPosters.com's most popular posters lists (top lists of Art, Nature, Movies, Music, Celebrities, and Sports posters) and pretested to be equally liked by European American and East Asian college students.

Procedure

Participants completed three tasks while having their brain activity measured in an fMRI scanner. Employing a similar paradigm as past fMRI work on choice-related attitude change

[6] These participants were recruited as part of a larger study of cross-cultural variations (n=635).

(Jarcho et al., 2011; Kitayama et al., 2013; Sharot et al., 2009), participants first completed a pre-choice rating task, followed by a choice task, and finally they completed the post-choice rating task. In the pre-choice rating task, participants were presented with a set of 72 posters to evaluate for themselves and 72 posters to evaluate for their friend. Posters were presented one at a time and for each poster participants were instructed to either rate how much they like the poster or rate how much their friend would like the poster on a 5-point scale (1=least likeable, 5=most likeable). Assignment of the two sets of 72 posters to the self and friend conditions were counterbalanced such that half of the participants evaluated Set A for the self and Set B for the friend and the other half were given the opposite. Trials were pseudo-randomized such that participants saw between 2-6 trials of a given trial type in a row to reduce frame-switching burden. I also included a cue (jittered presentation between 1 and 4 sec, M=1.875, SD=1.064) prior to each trial indicating whether the next trial would be a self trial or friend trial.

In the choice task, participants were presented with pairs of posters and selected one poster from each pair. For half of the pairs participants selected the poster that they wanted (i.e., self choices), and for the other half they selected a poster for their friend (i.e., friend choices). Because I was primarily interested in neural processes involved in making difficult choices that are more likely to elicit negative arousal, conflict, and choice-related attitude change, I used an algorithm to pair posters together such that each participant made 30 "difficult-self" choices, 30 "difficult-friend" choices, 6 "easy-self" choices, and 6 "easy-friend" choices. First, 12 posters from the self condition were paired together such that each pair of posters were rated in the pre-choice rating task at least 2 apart in the self condition (e.g., the participant rated one poster a "4" and the other poster a "2"). Next, the remaining 60 posters from the self condition were paired together into 30 pairs of posters such that each pair of posters were rated nearly identical in the

pre-choice rating task (e.g., the participant rated both posters a "4" or rated one poster a "4" and the other poster a "3"). This pairing procedure was then repeated for the posters in the friend condition (i.e., posters where the participant rated how much their friend liked the poster). The choice task also included a pseudo-randomized trial order such that participants saw between 2-6 trials of a given trial type. I also included a cue (jittered presentation between 1 and 4 sec, M=1.875, SD=1.064) prior to each trial indicating whether the next trial would be a self trial or friend trial. It was explained that one of the 36 posters chosen by the participant for themselves would be randomly selected and given to the participant at the end of the session and one of the 36 posters chosen for the friend would also be randomly selected and the participant could give the poster to their friend as a gift; so the choices were incentive compatible with real values. Finally, in the post-choice rating task, participants repeated the rating task described above.

fMRI Data Acquisition

Scanning was performed using a Philips 3 Tesla MRI scanner (Phillips Medical Systems, Andover, Massachusetts). T2*-weighted echo planar gradient-recall echo volumes (echo time=30ms, repetition time=2000ms, 64x64 matrix, flip angle=90 degree, field of view=22cm, 42 contiguous 3mm axial slices per volume), were acquired for each task. Five additional volumes were discarded at the beginning of each run to allow for stabilization of the MRI signal. A high-resolution T1-weighted structural image was also obtained to provide for more precise anatomical localization.

Functional MRI data analysis

Preprocessing of data was completed using SPM8 (Wellcome Department of Cognitive Neurology, London, UK). Functional volumes were slice time corrected to account for temporal differences in slice acquisition time, realigned to correct for head motion, and spatially

normalized to a standard template based upon the Montreal Neurological Institute (MNI) reference brain using VBM8 toolbox and DARTEL high dimensional warping. Participants were excluded from analysis if their head motion exceeded 3mm maximum Euclidean displacement. Because RSA analysis examines patterns of activation across voxels, I did not apply any smoothing to the data.

ROI Definition

In this study I was interested in processing of choice information in brain regions implicated in thinking about the self, thinking about the mental state of others, and representing subjective value. In order to examine representations of choice information in these regions, I used the regions of interest (ROIs) previously identified in Chapters 2 and 3. Specifically, I used ROIs identified in Chapter 2 analyses as being involved in making choices for a close friend (left and right TPJ), ROIs identified in Chapter 2 as predicting choice-related attitude change (left and right vSTR), and ROIs in mPFC and PCC identified as being involved in thinking about the self (taken from Chua et al. [2011] and used in Chapter 3). I took the peak voxels from those studies and created a 5mm sphere around the peak voxel using MarsBaR (see Figure II).

Representational Similarity Analysis

The goal of RSA is to create representational matrices that track how well the multivariate patterns of activation on each trial "match" or "fit" with the patterns on all other trials, and then compare the patterns of activation with explicitly defined models of the task. For example, RSA could be used to examine how patterns of activation in mPFC match a model that defines trials as either being chosen or rejected (choice outcome). If the patterns of activation match the model, then it is likely that mPFC differentiates between chosen and rejected options and represents choice outcome. In the current study, I focused on four primary questions: 1) do

mPFC, PCC, or vSTR represent choice outcome (chosen versus rejected); 2) do mPFC, PCC, or TPJ represent choice target (self versus friend); 3) does representation of choice outcome and/or target change from pre-choice to post-choice; and 4) are these neural representations moderated by culture?

In all analyses, I constructed representational dissimilarity matrices (RDMs) that summarize the similarity of every trial with every other trial[7]. Similarity can be measured by comparing the pattern of neural activation within an ROI on one trial with another trial (neural RDM) or by comparing the presence/absence of certain types of information on one trial with another trial (model RDM). Each neural RDM can then be compared to each model RDM in order to test whether the patterns of activation represented in the neural RDM match the choice information represented in the model RDM. For example, if TPJ represents choice target, then patterns of neural activation within TPJ would be more similar for trials where participants evaluated choice options for the same target (i.e., both trials were self trials or both trials were friend trials) than for trials where participants evaluated choice options for different targets (i.e., one trial was a self trial and the other was a friend trial). The strength of the fit between the neural RDM and model RDM are then measured by correlating the two matrices. The stronger the correlation between the neural RDM and the model RDM, the greater the degree to which that brain region represents the information in the model RDM. If, for example, the neural RDM for TPJ was significantly correlated with the model RDM for choice target, then TPJ has been shown to differentiate between self and friend choices and therefore represents information about choice target.

[7] RDMs actually code for dissimilarity—so higher values mean the two trials are more dissimilar.

Model RDMs. I first constructed model RDMs for choice outcome and choice target. The model RDMs were created such that pairs of trials were coded as 0 if both trials in a pair contained the same information (e.g., both chosen options or both rejected options) and 1 if both trials contained different information (e.g., Trial A was chosen and Trial B was rejected). Separate RDMs were constructed for each run for each participant for both choice outcome and choice target[8]. For the choice outcome RDM, each cell in the matrix was coded as 0 if both trials were chosen, 0 if both trials were rejected, and 1 if one trial was chosen and the other rejected. For the choice target RDM, each cell in the matrix was coded as 0 if both trials were self choices, 0 if both trials were friend choices, and 1 if one trial was a self choice and the other trial was a friend choice.

Neural RDMs. In order to construct the neural RDMs, I first estimated the neural responses to each trial using general linear modeling (GLM; Worsley, Evans, Marrett, & Neelin, 1992; Worsley, Poline, Friston, & Evans, 1997) in SPM8. I constructed a separate GLM for each run with separate regressors for each trial as well as covariates to account for participant head motion. I then extracted the unsmoothed parameter estimates for each trial in each voxel of the a priori ROIs (mPFC, PCC, left TPJ, right TPJ, left vSTR, and right vSTR). For each ROI, I constructed a separate RDM for each participant and each run by correlating the pattern of activation within the ROI on each trial with every other trial. Because the RDM codes for dissimilarity, each pairwise comparison was coded as 1 minus the correlation. Values closer to 1 (or greater than 1) therefore represent a pattern that is very dissimilar (because the correlation

[8]The size of RDMs were dependent on how many trials in a given run participants responded to and thus each run contained a different number of trials. On average, participants responded on 94% of trials. Size of RDMs for a run ranged from 28 to 48 trials with a mean of 45.14 trials.

was weak or negative) and values closer to 0 therefore represent a pattern that is very similar (because the correlation was strong).

Second-level comparisons. I conducted two primary analyses with the model and neural RDMs. First, I examined whether, across all subjects, patterns of activation within mPFC, PCC, and vSTR represented choice outcome (i.e., whether options were chosen or rejected). Second, I examined whether, across all subjects, patterns of activation within mPFC, PCC, and TPJ represented choice target (i.e., whether the choice was being made for the self or a close friend). For both analyses, I examined whether patterns of neural activation in the ROIs identified above might increase from pre-choice to post-choice, as well as whether representation of choice content (or changes in the representation) might be influenced by culture.

In order to examine neural representation of choice outcome, I first computed the Spearman correlation for each run and each participant between the neural RDMs and the choice outcome RDM (e.g., I computed the correlation between participant 1's mPFC RDM for run 1 with participant 1's choice outcome RDM for run 1) and transformed the correlation values using a Fisher r-to-z transformation. I then computed the average correlation for all pre-choice runs for each participant as well as the average correlation for all post-choice runs for each subject.

In order to test whether the representation of choice outcome changes from pre-choice to post-choice, I then computed a difference score for each participant by subtracting each subject's average post-choice correlation between each neural RDM and the choice outcome RDM minus their average pre-choice correlation between each neural RDM and the choice outcome RDM (e.g., the average post-choice correlation between the mPFC RDM and the choice outcome RDM minus the average pre-choice correlation between the mPFC RDM and the choice outcome RDM).

I then ran a series of one-sample t-tests on the average pre-choice correlations, the average post-choice correlations, and the change scores (post-choice minus pre-choice) between each neural RDMs and the choice outcome RDM to test whether the neural representation of choice outcome was significant in the pre-choice rating task, in the post-choice rating task, or whether it changed significantly from pre-choice to post-choice. I examined the neural representations across all 83 subjects. In order to test for potential boundary conditions, I then ran a two-sample t-test to examine whether the representation of choice outcome differed for European Americans and East Asians and also tested whether the neural representations were significant for European Americans and East Asians separately. Finally, I repeated the above steps for the choice target RDM.

Results[9]

Analysis 1: Representation of choice outcome

Pre-choice rating task. I first examined whether patterns of activation in mPFC, PCC, vSTR, and TPJ would represent choice outcome (chosen versus rejected options) during the pre-choice rating task. While the choice outcome had not yet been determined, differentiation of the patterns of activation for chosen and rejected options could suggest that how these brain regions process choice information prior to the choice being made influences the outcome of the choice. During the pre-choice rating task, the relationship between mPFC and the choice outcome RDM was marginally significant for all 83 participants ($t(82)=1.80$, $p=.076$), although this effect was not significant when examining European Americans ($t(44)=1.48$, $p=.146$) and East Asians ($t(37)=1.04$, $p=.306$) separately, nor was there a significant cultural difference ($t(77.21)=0.19$, $p=.849$).

[9] Behavioral results have previously been reported in Chapter 2.

Additionally, the relationship between right TPJ and choice outcome was significant for all 83 participants ($t(82)=2.71$, $p=.008$). While there was not a significant cultural difference between the two groups ($t(78.31)=0.88$, $p=.384$), East Asians primarily drove the overall effect, such that right TPJ was significantly correlated with the choice outcome RDM for East Asians ($t(37)=2.46$, $p=.019$) but not European Americans ($t(44)=1.41$, $p=.167$).

While there was not a significant relationship between left vSTR and the choice outcome RDM across all 83 subjects ($t(82)=0.21$, $p=.837$), there was a significant effect for European Americans ($t(44)=2.02$, $p=.050$). There was not a significant relationship for East Asians ($t(37)=-0.42$, $p=.676$), and the cultural difference was not statistically significant ($t(72.52)=1.57$, $p=.122$). None of the other ROIs were significantly correlated with the choice outcome RDM during the pre-choice rating task.

Post-choice rating task. Second, I examined whether patterns of activation in the a priori ROIs would represent choice outcome (chosen versus rejected) during the post-choice rating task. Because the choice had been made at this time, differentiation of the patterns of activation for chosen and rejected options could suggest that these brain regions are representing the outcome of the choice. During the post-choice rating task, there was a significant relationship between mPFC and the choice outcome RDM for all 83 participants ($t(82)=2.37$, $p=.020$), and the direct cultural comparison was not statistically significant ($t(68.73)=0.72$, $p=.474$; see Figure IIIA). However, European Americans primarily drove the overall effect, such that mPFC was significantly correlated with the choice outcome RDM for European Americans ($t(44)=2.57$, $p=.014$) but not East Asians ($t(37)=0.93$, $p=.358$).

Additionally, there was a significant relationship between right TPJ and the choice outcome RDM for all 83 participants ($t(82)=2.32$, $p=.023$) and there was not a significant

cultural difference in the representation of choice outcome ($t(73.53)=0.46$, $p=.645$; see Figure IIIB). However, East Asians primarily drove the overall effect, such that there was a marginally significant correlation between right TPJ and choice outcome RDM for East Asians ($t(37)=1.76$, $p=.086$) but not European Americans ($t(44)=1.49$, $p=.144$). None of the other ROIs were significantly correlated with the choice outcome RDM during the post-choice rating task.

Change from pre-choice to post-choice. Third, I examined whether the representation of choice outcome might change from pre-choice to post-choice. However, none of the ROIs tested here showed a significant change in the correlation between the neural RDM and the choice outcome RDM. Nor were there any cultural differences in the change from pre-choice to post-choice.

Analysis 2: Representation of choice target

Pre-choice rating task. I first examined whether patterns of activation in mPFC, PCC, vSTR, and TPJ would represent choice target (self versus friend choices) during the pre-choice rating task. Participants were explicitly instructed to evaluate the choice options for themselves or a close friend, and thus differentiation of the patterns of activation for self and friend choices could suggest that these brain regions are representing the target of the choice. During the pre-choice rating task, mPFC, PCC, and left TPJ were significantly correlated with the choice target RDM for all subjects ($t(82)=3.94$, $p<.001$; $t(82)=5.75$, $p<.001$; $t(82)=4.68$, $p<.001$; respectively). The representation of choice target in mPFC, PCC, and left TPJ were also not moderated by culture ($t(78.63)=1.22$, $p=.225$; $t(74.41)=0.48$, $p=.630$; $t(67.32)=1.43$, $p=.158$, respectively). The relationships between mPFC, PCC, and left TPJ and the choice target RDM were significant for both European Americans ($t(44)=2.08$, $p=.043$; $t(44)=4.14$, $p<.001$; $t(44)=2.90$, $p=.006$;

respectively) and East Asians (t(37)=3.57, p=.001; t(37)=3.97, p<.001; t(37)=3.72, p<.001; respectively).

There was also a significant relationship between right TPJ and the choice target RDM (t(82)=2.11, p=.038), and this overall effect was not moderated by culture (t(70.94)=0.23, p=.817). However, European Americans primarily drove the overall effect, such that there marginally significant correlation between right TPJ and the choice target RDM for European Americans (t(44)=1.90, p=.065) but not East Asians (t(37)=1.12, p=.270). None of the other ROIs were significantly correlated with the choice target RDM during the pre-choice rating task.

Post-choice rating task. Second, I examined whether patterns of activation in the a priori ROIs would represent choice target during the post-choice rating task. During the post-choice rating task, mPFC, PCC, and left TPJ were significantly correlated with the choice target RDM (t(82)=5.22, p<.001; t(82)=3.37, p=.001; t(82)=3.97, p<.001; respectively). The representation of choice target in mPFC, PCC, and left TPJ were also not moderated by culture (t(69.57)=0.69, p=.490; t(76.89)=0.19, p=.847; t(74.39)=0.27, p=.791, respectively). The relationships between mPFC, PCC, and TPJ and the choice target RDM were significant for both European Americans (t(44)=3.80, p<.001; t(44)=2.40, p=.021; t(44)=2.90, p=.006; respectively) and East Asians (t(37)=3.59, p<.001; t(37)=2.33, p=.025; t(37)=2.69, p=.011; respectively).

Additionally, there was a significant relationship between right TPJ and the choice target RDM (t(82)=2.78, p=.007) and this overall effect was not moderated by culture (t(79.90)=0.67, p=.502). However, European Americans primarily drove the overall effect, such that right TPJ was significantly correlated with the choice target RDM for European Americans (t(44)=2.43, p=.019) but not East Asians (t(37)=1.42, p=.164). None of the other ROIs were significantly correlated with the choice target RDM during the post-choice rating task.

Change from pre-choice to post-choice. Third, I examined whether the representation of choice target might change from pre-choice to post-choice. However, none of the ROIs tested here showed a significant change in the correlation between the neural RDM and the choice target RDM. Nor were there any cultural differences in the change from pre-choice to post-choice.

Discussion

Using brain data from individuals who evaluated choice options both before and after making difficult choices either for the self or a close friend, I found that information about choice outcome (chosen versus rejected) was represented in mPFC and TPJ. Although the cultural difference was not statistically significant, representation of choice outcome in mPFC appears to be primarily driven by European Americans, whereas representation of choice outcome in TPJ appears to be primarily driven by East Asians. Additionally, information about choice target (self versus friend) is represented in mPFC, PCC, and TPJ for both European Americans and East Asians.

Interestingly, representation of choice outcome was strongest during the post-choice rating task, whereas representation of choice target was consistent across both the pre-choice and post-choice rating tasks. Participants were explicitly instructed to evaluate the choice options for themselves or a close friend, and thus consistency in the representation of choice target across the pre-choice and post-choice rating tasks could be due to the fact that this information was explicitly presented before each trial.

Representation of choice outcome, however, is only represented during the post-choice rating task (and not during the pre-choice rating task). Representation during the pre-choice rating task would suggest that multivariate patterns are potentially influencing the choice, but

since I only found the effect during the post-choice rating task, it is more likely that these brain regions are representing the outcome of the choice (rather than driving the choice).

Choice and ownership

For European Americans, multivariate patterns in mPFC differentiate between chosen and rejected options only after the choice has been made (but not prior to the choice). This suggests that, rather than driving or predicting choice outcome, multivariate patterns in mPFC reflect the choice outcome and represent information about whether a choice option was chosen or not. mPFC plays an integral role in processing self-relevance of stimuli (Kim & Johnson, 2012, 2014; van der Meer et al., 2010), and thus one interpretation of these findings is that chosen options are being associated with the self. Previous research has found that implicit associations between chosen options and the self increase after a choice has been made, and these increases in turn predict attitude change following the choice (Gawronski et al., 2007). Given the importance of choice in American culture as an action that reflects one's internal attributes and gives the individual an opportunity to express their uniqueness (Kim & Sherman, 2007; Markus & Schwartz, 2010), it is possible that European Americans are integrating their self-concept into every choice, and this is being reflected in multivariate patterns in mPFC.

Culture and representation of choice outcome

While European Americans represent choice outcome in mPFC, East Asians represent choice outcome in TPJ. Although the representation of choice outcome in mPFC and TPJ in European Americans and East Asians were not significantly different, this result is consistent with a recent meta-analysis that finds that European Americans are more likely to recruit self-processing regions when making social judgments, whereas East Asians are more likely to recruit mentalizing regions when making social judgments (Han & Ma, 2014). It goes beyond

prior work by showing that previously identified univariate activation of these brain regions extends to multivariate patterns of activation.

This distinction is also interesting because, while mPFC only differentiates between chosen and rejected options after the choice has been made, TPJ differentiates between chosen and rejected options both prior to the choice and after it has been made. This suggests that TPJ might actually represent choice information that influences the choice outcome. Given previous theorizing on cultural differences in the importance of social preferences and norms in driving behavior (Markus & Kitayama, 2003; Riemer et al., 2014), it is possible that multivariate representation of others' preferences in TPJ during the pre-choice rating task is influencing which options East Asian participants choose.

Self-processing and subjective value

This work builds upon models of decision-making that posit that processing self-relevance and subjective value are key functions involved in decision-making. Previous work has shown that mPFC is involved in thinking about and evaluating the self (Amodio & Frith, 2006; Denny et al., 2012; Northoff et al., 2006b; Schmitz & Johnson, 2007) as well as representing subjective value (Bartra et al., 2013; Knutson et al., 2005). However, thinking about the self is a broad psychological process that can include a number of distinct sub-processes, many of which could be important for decision-making. One hypothesized function of mPFC is the representation of self-relevance, and greater activation in mPFC has often been interpreted as suggesting that stimuli are perceived as more self-relevant (Kim & Johnson, 2012, 2014). In the current study, representations of choice outcome and choice target in mPFC are sensitive to time and culture, which suggests that neural representation of self-relevance is malleable and context-dependent.

Limitations and Future Directions

Decision-making is often complex and there are often many attributes and dimensions on which a choice option could be evaluated. The current work only focused on two types of choice information—namely whether the option was chosen and whether the target of the choice was the self or a close friend. Thus, this study barely scratches the surface of attributes and dimensions that could be represented in the brain. While beyond the scope of the current study, future work should attempt to examine how the brain represents other dimensions of choice. For example, univariate activation in anterior insula is recruited when people are presented with the cost of a potential consumer purchase (Knutson et al., 2007) and it is therefore possible that anterior insula might be involved in representing information about cost.

The current work also only examines a few a priori regions of interest (mPFC, PCC, TPJ, and vSTR). It is likely that many other brain regions are also involved in representing choice information. For example, visual cortex is almost surely involved in representing information about visual features of choice options. Future work should expand upon this work by examining how other brain regions might represent choice information.

Another limitation of the current research is that it is correlational. Specifically, while the current work suggests that cortical regions including mPFC, PCC, and TPJ are involved in representing choice information, it doesn't offer any insight into how the brain is using this information to actually make the final decision. Does information about choice outcome or choice target change how the chooser evaluates the choice options? And does it have downstream consequences for what other information the chooser attends to, or what other brain regions are involved in the decision-making process? These questions are beyond the scope of

the current study and thus future research should attempt to unpack the specific roles of these brain regions in making the choice.

Finally, future research should examine whether these same brain regions represent different types of choices, and whether this has consequences for real-world behaviors. Multivariate patterns in vmPFC process content of persuasive health messages and predict subsequent changes in health behavior (Pegors, Tompson, O'Donnell, & Falk, under review). It would be interesting to examine whether mPFC and TPJ are also involved in health decisions such as whether to quit smoking or choose the healthy food option (and whether involvement of these regions differs for people from individualistic and collectivistic cultures).

Conclusion

This research is the first to directly examine how people from different cultures represent choice information in the brain. It suggests that brain regions involved in thinking about the self as well as thinking about the mental states of others represent two important dimensions of choice—whether the option was chosen and who the choice is being made for. Moreover, the brain regions that represent choice information depend on the cultural background of the chooser. These findings advance understanding of how cortical structures including mPFC, PCC, and TPJ process information about choice options and how processing of choice information is influenced by culture.

Figure IV.1. Regions of interest used in RSA analysis.

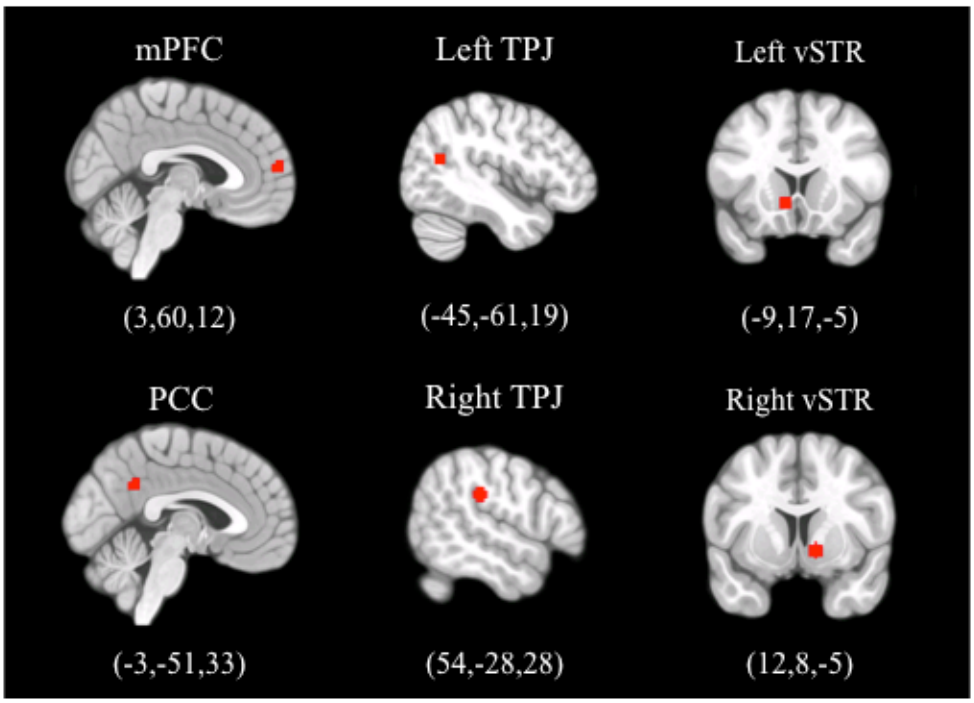


Figure IV.2. Multivariate representations of choice outcome.

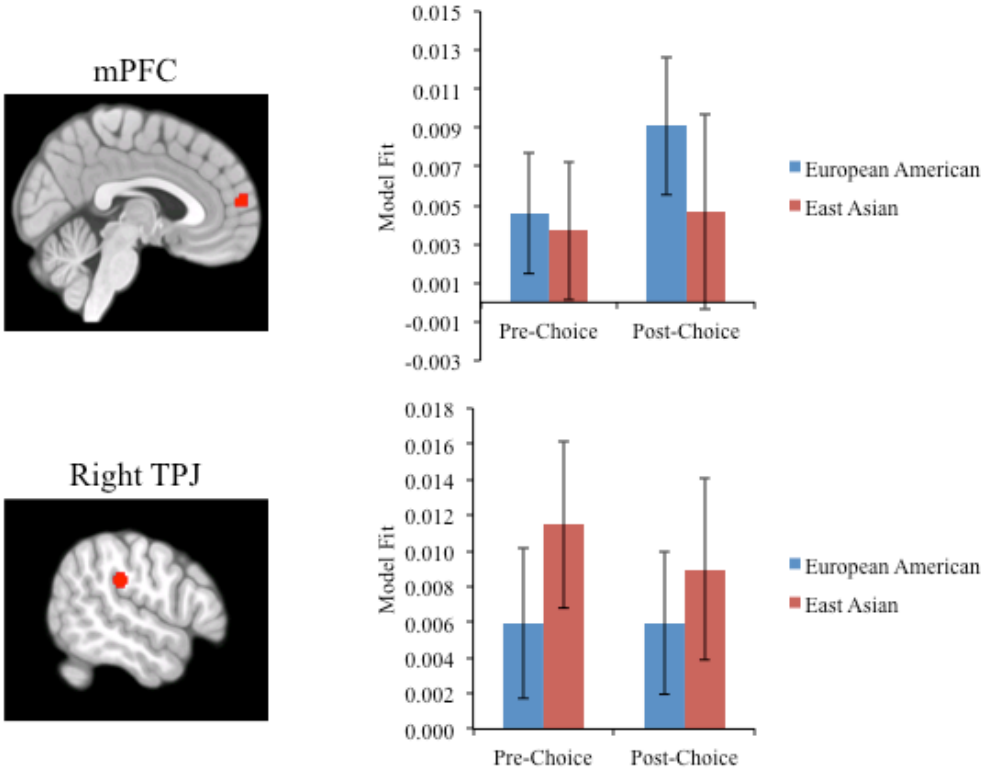
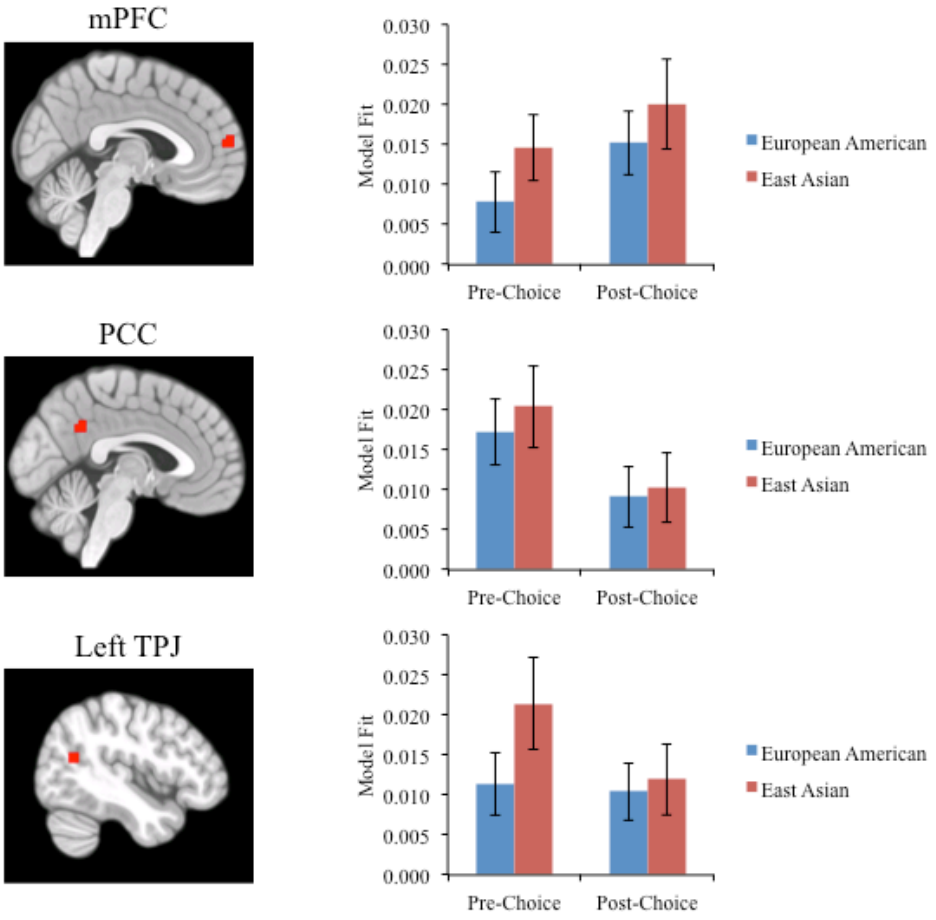


Figure IV.3. Multivariate representations of choice target.



CHAPTER V

Discussion

How do people make a choice when the options are seemingly equal? And how do psychological processes occurring both as a part of the decision-making process and after the decision has been made influence attitudes towards the choice options? Finally, does culture influence the processes underlying decision-making and attitude change? The current work utilizes neuroimaging to examine these important questions and provides evidence for key brain regions and networks that support decision-making and attitude change for both the self and close others. A key strength of this research is that it examines both social and biological processes, as well as the interaction between the two.

In Chapter 2, I measured neural activation during decision-making and found that PCC and vSTR predicted attitude change for European Americans but not East Asians. Moreover, both dACC and aINS were recruited when people make difficult (versus easy) choices for the self and a close friend, whereas mentalizing regions were recruited when people make difficult choices for a close friend (versus self choices). In Chapter 3, I found that increases in connectivity between mPFC and PCC from pre-choice to post-choice predicted attitude change. In Chapter 4, I found that mPFC represented information about choice outcome (chosen versus rejected) for European Americans whereas TPJ represented information about choice outcome for East Asians. Additionally, mPFC, PCC, and TPJ represented information about choice target (self versus friend) for both European Americans and East Asians. This research advances

understanding of how culture shapes the way in which people evaluate choice options and make choices.

Cultural Similarities and Differences

Chapters 2 and 4 provide evidence for both similarities and differences in the brain regions involved in decision-making for people from individualistic and collectivistic cultures. In Chapter 2, both European Americans and East Asians recruit dACC and aINS when making difficult choices for the self and a close friend as well as show some similarities in recruitment of PCC and TPJ during friend choices. And in Chapter 4, both European Americans and East Asians represent information about choice target (self versus friend) in mPFC, PCC, and TPJ. This suggests that there are similarities in how people from individualistic and collectivistic cultures evaluate choice options and make difficult choices. One possible interpretation of these findings is that both European Americans and East Asians evaluate choice options in reference to the target (self or close friend) and experience conflict between choice options as aversive.

There are also some interesting cultural differences in Chapters 2 and 4. East Asians show strong activation of TPJ when making choices for a close friend (Chapter 2) and also appear to represent information about choice outcome and choice target in TPJ (Chapter 4). By contrast, European Americans are somewhat less likely to recruit TPJ when making choices for a close friend (Chapter 2) and represent information about choice outcome in mPFC (Chapter 4). It is interesting that in some cases, European Americans and East Asians use mPFC and TPJ to represent the same type of information (i.e., choice target), whereas in other cases, mPFC and TPJ are differentially recruited to represent choice information (i.e., choice outcome). This suggests that recruitment of these regions is malleable and context-dependent, and may be

sensitive to both the cultural background of the chooser as well as the type of information being evaluated.

This research is also consistent with previous evidence that people from individualistic cultures are more likely to recruit regions involved in thinking about and evaluating the self when making social judgments, whereas people from collectivistic cultures are more likely to recruit regions involved in taking the perspective of others when making social judgments (Han & Ma, 2014; Ma et al., 2012). It expands upon this work by showing that previously reported cultural differences in social judgments extend to consumer decision-making. Thus, people from individualistic cultures primarily make choices people individualistic cultures primarily make decisions by focusing internally and considering their own preferences, whereas people from collectivistic cultures are more likely to consider others' preferences when making decisions.

While European Americans primarily recruit mPFC to make difficult choices and East Asians primarily recruit TPJ to make difficult choices, these differences are not statistically significant. In both Chapters 2 and 4 there is frequently a significant effect for one group but not the other, but the direct cultural comparison is not significant. While the differences are small (with effect sizes in the 0.15 to 0.30 range), they are consistent and always trend in the same direction. It is possible that the East Asian participants in our study had adjusted to American culture, and thus were more likely to think and behave similarly to our European American participants.

Another possibility is that the East Asian participants who self-selected to come to the United States might be more likely to make choices that are particularly individualistic or focused on personal goals. The East Asian participants in Chapters 2 and 4 made a very individualistic choice to leave their families and come to the United States for college, and thus their choice behavior might be more similar to the choice behavior in our European American sample, even when they report being more collectivistic on other dimensions. This might explain the reliably small effects found in the current study, and why the cultural differences found here are smaller than in other studies with similar samples (e.g., Kitayama, King, et al., 2014). Future work should examine whether these cultural differences are larger when comparing European Americans with East Asians born in and currently living in East Asia.

Choice-Related Attitude Change

Chapters 2 and 3 also advance understanding of how in-choice and post-choice processes contribute to choice-related attitude change. This research advances our understanding of how people change their attitudes during and after the choice. I replicate past work on neural mechanisms underlying choice-related attitude change (Jarcho et al., 2011; Kitayama et al., 2013), which, in light of recent research questioning the replicability of fMRI research (Barch & Yarkoni, 2013; Eklund, Nichols, & Knutsson, 2016) is important for establishing the robustness of the relationship between vSTR and PCC and choice-related attitude change. Beyond replicating this work, however, this dissertation extends past work in a number of key ways.

First, in Chapter 2 I show that the link between vSTR and attitude change previously shown in European Americans making choices for themselves extends to choices made for a close friend. Second, in Chapter 2 I show that this link between vSTR and attitude is absent in East Asians for both self and friend choices, with a marginally significant difference between the

two cultural groups. Third, in Chapter 3 I show that changes in functional connectivity between mPFC and PCC track choice-related attitude change. Finally, in Chapters 2 and 3 I extend past work and show that both in-choice and post-choice processes contribute to attitude change.

While Chapter 3 was restricted to American participants, and it is therefore difficult to conclude anything about potential generalizability across cultures, evidence from Chapter 4 shows that there are some differences in how people from individualistic and collectivistic cultures recruit mPFC when evaluating choice options. It is therefore possible that East Asian participants would show a weaker relationship between mPFC-PCC connectivity and attitude change.

It is worth noting that I did not replicate previous work that has shown that increases in activation in reward processing regions from the pre-choice rating task to the post-choice rating task track choice-related attitude change (Izuma et al., 2010; Sharot et al., 2009). While potentially troublesome, there are a number of key differences between the current study and past work that might shed light on why this occurred. First, previous work had participants make experiential choices where participants were specifically instructed to imagine how pleasurable the experience would be (Sharot et al., 2009) whereas the current work instructed participants to choose which option they would prefer to own. Previous research therefore placed a much greater emphasis on the hedonic aspects of the choice options, which may have amplified any effect of reward processing on the pre-choice and post-choice evaluation of the choice options.

Second, previous work had participants imagine these experiences but didn't actually give participants the option they chose. In the current work participants were instructed that they would receive one of the options they chose at the end of the study. The hypothetical nature of past work might also amplify the effect of internally focused reward processing (e.g., how much

would I enjoy eating this food?) whereas the more incentive-compatible procedure employed in the current work might amplify other more external aspects of the choice (e.g., what would this poster look like on my wall next to my other art?).

Social Psychological Theories of Attitude Change

This work also sheds light on a long-standing debate about the psychological mechanisms underlying choice-related attitude change. Previous work in social psychology has primarily focused on three potential mechanisms: cognitive conflict, negative arousal, and/or self-processing. Some theories primarily focus on the role of cognitive conflict and negative arousal in motivating attitude change (Festinger, 1957), whereas others focus on the role of self-processing in driving attitude change (Bem, 1967). Other theories of attitude change posit that it is the combination of cognitive conflict, negative arousal, and self-processing that produces attitude change (Aronson, 1969; Steele, 1988). For example, cognitive conflict that is self-relevant and threatens positive views of the self is negatively arousing, which motivates the individual to shift their attitudes to reduce the self-threat (Steele, 1988). The current work is most consistent with the latter type of theory, in that brain regions implicated in cognitive conflict, negative arousal, and self-processing all seem to be involved in making difficult choices and promoting choice-related attitude change. Furthermore, it is least consistent with theories that argue that only cognitive conflict or only self-processing are involved in choice-related attitude change.

Taken together, the current work demonstrates that brain regions involved in thinking about and evaluating the self, recalling episodic or autobiographical memories, and tracking and updating subjective value are associated with choice-related attitude change. This research is consistent with the biosocial model of affective decision-making (Kitayama & Tompson, 2015),

in that both in-choice affective processing of the choice and post-choice cognitive processing of the choice options promote and facilitate choice-related attitude change.

This research is also consistent with research that has examined brain regions involved in attitude change in other domains. While choice-related attitude change is primarily internally driven (i.e., an individual's own actions drive the attitude change), other theories of attitude change focus on when and how people shift their attitudes in response to external influence (e.g., to conform with one's peers or in response to a persuasive message). Despite these differences, many of the same brain regions identified in Chapters 2 and 3 as being involved in choice-related attitude change are also involved in persuasion-induced attitude change as well as attitude change due to social influence (Cascio, Scholz, & Falk, 2015). For example, vSTR and ventral mPFC are both associated with changes in ratings of phone apps after being shown what a group of peers rated the apps (Cascio, O'Donnell, Bayer, Tinney, & Falk, 2015). Likewise, mPFC and PCC activation predicts subsequent changes in behavior in response to persuasive health messages (Falk, Berkman, Whalen, & Lieberman, 2011).

Beyond Univariate Activation

Chapter 2, as well as most of the literature on brain regions involved in decision-making, focuses on how average activation within a specific brain region (or set of brain regions) is involved in decision-making. While this provides useful information about which brain regions are activated more during one type of choice than another, or which brain regions are more strongly associated with attitude change, it also misses out on a lot of additional nuance in how the brain processes information and makes decisions. Chapter 3 examines how functional connectivity between brain regions changes from pre-choice to post-choice and whether changes in how brain regions communicate with one another relate to attitude change. Chapter 4

examines how patterns of activation within a specific brain region represent information about the choice options (above and beyond any effect of average activation). Thus, Chapters 3 and 4 both move beyond basic analysis of how single brain regions are involved in decision-making.

These two novel approaches have the potential to advance our understanding of the brain. Brain activation is more than just a single brain region firing. The average signal within a brain region represents the firing of thousands of neurons, and neuronal firing communicates information to other neurons within that region as well as with other brain regions. Thus, analyzing patterns of activation (both within a single brain region as well as across brain regions) can help develop a richer understanding of how the brain as a whole is processing information related to the choice and subsequent attitude change.

Moreover, multivariate patterns within a brain region are thought to be much more closely related to the actual firing-patterns of clusters (or populations) of neurons in a brain region and thus track how that brain region (and the neurons within that brain region) is processing and representing information (Mur et al., 2009). This research is the first to examine how people from different cultures represent choice information in the brain, and thus advances our understanding of the psychological processes underlying choice and attitude change.

Nature versus Nurture

Scientists have long debated whether behavior is driven more by an individual's biological make-up or their social environment (Darwin, 1859; Herrnstein & Murray, 1994; Mead, 1928; Nisbett et al., 2012). Recent work in cultural neuroscience has argued that these two factors might not be oppositional, and instead the interaction between biology and environment might strongly influence behavior (Kitayama & Uskul, 2011). In this model, culture and biology mutually influence each other, such that culture creates the environment for particular biological

factors to thrive, and biology in turn influences what cultural beliefs, norms, and values are likely to emerge in a particular environment. The current work adds to this discussion by showing that brain regions involved in decision-making and neural representations of choice information differ for people from individualistic and collectivistic cultures.

Implications for decision-making

Taken together, these three studies show that brain regions involved in thinking about and evaluating the self, recalling episodic or autobiographical memories, taking the perspective of another person, tracking and updating subjective value, and monitoring conflict and negative arousal are all involved in making difficult choices and representing information about those choices.

One potentially confusing part of the current work is the specific roles that are being served by mPFC and PCC. By their very nature, cortical regions are likely to be involved in multiple cognitive processes, and mPFC and PCC have been implicated in many closely related processes including processing subjective value/reward (Bartra et al., 2013; Knutson et al., 2005; Pearson et al., 2009), abstract representations of the self (van der Meer et al., 2010), evaluating self-relevance of information (Chua et al., 2011), and retrieving episodic memories (Sajonz et al., 2010). A common underlying link between these processes is that they all involve comparing some information to the self, whether it is estimating the value of an item to the self, evaluating whether information is related to the self or included in abstract representations of the self, or connecting the information to memories about the self.

Recent work has attempted to differentiate between the functional organization of different subregions of mPFC. Anterior mPFC is primarily involved in social judgments (i.e., thinking about the self and close others), reward processing, and decision-making, whereas

posterior mPFC is primarily involved in motor and inhibitory processes (de la Vega et al., 2016). Within anterior mPFC (where the ROI in the current work is located), there are further subdivisions, such that dorsal anterior mPFC is primarily involved in social judgments (i.e., thinking about the self and close others) and ventral anterior mPFC is primarily involved in decision-making and reward processing (de la Vega et al., 2016). This work is consistent with neuroeconomics research that finds that ventral anterior mPFC is involved in integrating information to update subjective value of choice options to the self (Bartra et al., 2013). One limitation of the current work is that I only test one ROI within mPFC, which is also located near the intersection of the dorsal and ventral anterior mPFC subregions identified in the de la Vega meta-analysis. It is therefore difficult to differentiate between these separate functions and determine which of these is occurring within the mPFC ROI used in this research. Future research might be able to use localizer tasks to differentiate between sub-regions in mPFC as well as PCC that are differentially involved in computation of reward, self-relatedness, or retrieval of autobiographical memories.

Conclusion

In summary, the current work examines how social and biological factors influence the decision-making process. Perhaps more importantly, it shows that social and biological factors influence one another, such that people from different cultures recruit different brain regions when processing choice information and making difficult choices for a close friend. My research examines the role of social and biological factors in three key ways: how in-choice neural activation contributes to decision-making and attitude change when people from individualistic versus collectivistic cultures make choices for themselves and close others (Chapter 2), how functional connectivity between brain regions contributes to attitude change (Chapter 3), and

how different brain regions represent choice information for people from individualistic and collectivistic cultures (Chapter 4).

This research advances understanding of how people from diverse cultural backgrounds make choices, which is critical for making extant research more broadly applicable. This research has broad implications for how people from different cultures make choices across a variety of real-world domains, including health choices (e.g., which cancer treatment to receive), financial choices (e.g., which stock to buy or sell), and relationship choices (e.g., who to marry). Ultimately, the choices we make have a far-reaching impact on those around us, and understanding how and why people make certain choices, and how the neural processes underlying these choices may differ across cultures, can lead to greater health and well-being for both the chooser as well as the population as a whole.

Appendix

Appendix A
Abbreviated 20-Item Version of Singelis (1994) Self-Construal Scale

Item	Subscale
1. I always try to have my own opinions.	Independence
2. I am comfortable with being singled out for praise or rewards.	Independence
3. The best decisions for me are the ones I made by myself.	Independence
4. In general I make my own decisions.	Independence
5. I act the same way no matter who I am with.	Independence
6. I am not concerned if my ideas or behavior are different from those of other people.	Independence
7. I always express my opinions clearly.	Independence
8. Being able to take care of myself is a primary concern for me.	Independence
9. I enjoy being unique and different from others in many respects.	Independence
10. I do my own thing, regardless of what others think.	Independence
11. I am concerned about what people think of me.	Interdependence
12. In my own personal relationships I am concerned about the other person's status compared to me and the nature of our relationship.	Interdependence
13. I think it is important to keep good relations among one's acquaintances.	Interdependence
14. I avoid having conflicts with members of my group.	Interdependence
15. When my opinion is in conflict with that of another person's, I often accept the other opinion.	Interdependence
16. I respect people who are modest about themselves.	Interdependence
17. I will sacrifice my self-interest for the benefit of the group I am in.	Interdependence
18. I often have the feeling that my relationships with others are more important than my own accomplishment.	Interdependence
19. I feel my fate is intertwined with the fate of those around me.	Interdependence
20. Depending on the situation and the people that are present, I will sometimes change my attitude and behavior.	Interdependence

References

Alós-Ferrer, C., & Shi, F. (2015). Choice-induced preference change and the free-choice paradigm: A clarification. *Judgment and Decision Making*, *10*(1), 34–49. http://doi.org/10.2139/ssrn.2062507

Amodio, D. M. (2010). Can Neuroscience Advance Social Psychological Theory? Social Neuroscience for the Behavioral Social Psychologist. *Social Cognition*, *28*(6), 695–716. http://doi.org/10.1521/soco.2010.28.6.695

Amodio, D. M., & Frith, C. D. (2006). Meeting of minds: the medial frontal cortex and social cognition. *Nature Reviews Neuroscience*, *7*(4), 268–277. http://doi.org/10.1038/nrn1884

Aronson, E. (1969). The Theory of Cognitive Dissonance: A Current Perspective. In *Advances in Experimental Social Psychology* (Vol. 4, pp. 1–34).

Barch, D. M., & Yarkoni, T. (2013). Introduction to the special issue on reliability and replication in cognitive and affective neuroscience research. *Cognitive, Affective & Behavioral Neuroscience*, *13*(4), 687–9. http://doi.org/10.3758/s13415-013-0201-7

Bartra, O., McGuire, J. T., & Kable, J. W. (2013). The valuation system: a coordinate-based meta-analysis of BOLD fMRI experiments examining neural correlates of subjective value. *NeuroImage*, *76*, 412–27. http://doi.org/10.1016/j.neuroimage.2013.02.063

Bem, D. J. (1967). Self-perception: An alternative interpretation of cognitive dissonance phenomena. *Psychological Review*, *74*, 183–200. http://doi.org/10.1037/h0025146

Berridge, K. C., Robinson, T. E., & Aldridge, J. W. (2009). Dissecting components of reward: "liking", "wanting", and learning. *Current Opinion in Pharmacology*. http://doi.org/10.1016/j.coph.2008.12.014

Brehm, J. W. (1956). Postdecision changes in the desirability of alternatives. *The Journal of*

Abnormal and Social Psychology, *52*, 384–389. http://doi.org/10.1037/h0041006

Carter, R. M., Bowling, D. L., Reeck, C., Huettel, S. A., Lee, D., Danchin, E., … Ladurner, G. (2012). A distinct role of the temporal-parietal junction in predicting socially guided decisions. *Science (New York, N.Y.)*, *337*(6090), 109–11. http://doi.org/10.1126/science.1219681

Cascio, C. N., O'Donnell, M. B., Bayer, J., Tinney, F. J., & Falk, E. B. (2015). Neural correlates of susceptibility to group opinions in online word-of-mouth recommendations. *Journal of Marketing Research*, 150109125622007. http://doi.org/10.1509/jmr.13.0611

Cascio, C. N., Scholz, C., & Falk, E. B. (2015). Social influence and the brain: persuasion, susceptibility to influence and retransmission. *Current Opinion in Behavioral Sciences*, *3*, 51–57. http://doi.org/10.1016/j.cobeha.2015.01.007

Chen, M. K., & Risen, J. L. (2010). How choice affects and reflects preferences: revisiting the free-choice paradigm. *Journal of Personality and Social Psychology*, *99*(4), 573–594. http://doi.org/10.1037/a0020217

Chua, H. F., Gonzalez, R., Taylor, S. F., Welsh, R. C., & Liberzon, I. (2009). Decision-related loss: regret and disappointment. *Neuroimage*, *47*(4), 2031–40. http://doi.org/10.1016/j.neuroimage.2009.06.006

Chua, H. F., Ho, S. S., Jasinska, A. J., Polk, T. a, Welsh, R. C., Liberzon, I., & Strecher, V. J. (2011). Self-related neural response to tailored smoking-cessation messages predicts quitting. *Nature Neuroscience*, *14*, 426–427. http://doi.org/10.1038/nn.2761

Cooper, J., & Fazio, R. H. (1984). A new look at dissonance theory. In *Advances in Experimental Social Psychology*.

Cooper, J., & Hogg, M. A. (2007). Feeling The Anguish Of Others: A Theory Of Vicarious

Dissonance. *Advances in Experimental Social Psychology*, *39*, 359–403. http://doi.org/10.1016/S0065-2601(06)39007-7

Darwin, C. (1859). *On the Origin of Species*. *On the Origin of Species*. http://doi.org/10.4324/9780203509104

de la Vega, A., Chang, L. J., Banich, M. T., Wager, T. D., & Yarkoni, T. (2016). Large-Scale Meta-Analysis of Human Medial Frontal Cortex Reveals Tripartite Functional Organization. *Journal of Neuroscience*, *36*(24), 6553–6562. http://doi.org/10.1523/JNEUROSCI.4402-15.2016

Denny, B. T., Kober, H., Wager, T. D., & Ochsner, K. N. (2012). A Meta-analysis of Functional Neuroimaging Studies of Self- and Other Judgments Reveals a Spatial Gradient for Mentalizing in Medial Prefrontal Cortex. *Journal of Cognitive Neuroscience*, *24*, 1742–1752. http://doi.org/10.1162/jocn_a_00233

DeWall, C. N., Chester, D. S., & White, D. S. (2015). Can acetaminophen reduce the pain of decision-making? *Journal of Experimental Social Psychology*, *56*, 117–120. http://doi.org/10.1016/j.jesp.2014.09.006

Eisenberger, N. I., & Lieberman, M. D. (2004). Why rejection hurts: A common neural alarm system for physical and social pain. *Trends in Cognitive Sciences*, *8*(7), 294–300. http://doi.org/10.1016/j.tics.2004.05.010

Eklund, A., Nichols, T. E., & Knutsson, H. (2016). Cluster failure: Why fMRI inferences for spatial extent have inflated false-positive rates. *Proceedings of the National Academy of Sciences*, *113*(28), 7900–7905. http://doi.org/10.1073/pnas.1602413113

Elliot, A. J., & Devine, P. G. (1994). On the Motivational Nature of Cognitive Dissonance: Dissonance as Psychological Discomfort. *Journal of Personality and Social Psychology*,

67(3), 382–394.

Falk, E. B., Berkman, E. T., Whalen, D., & Lieberman, M. D. (2011). Neural activity during health messaging predicts reductions in smoking above and beyond self-report. *Health Psychology : Official Journal of the Division of Health Psychology, American Psychological Association*, *30*(2), 177–185. http://doi.org/10.1037/a0022259

Festinger, L. (1957). An introduction to the theory of dissonance. *A Theory of Cognitive Dissonance*, 1–31. http://doi.org/10.1037/10318-001

Feyers, D., Collette, F., D'Argembeau, A., Majerus, S., & Salmon, E. (2010). Neural networks involved in self-judgement in young and elderly adults. *NeuroImage*, *53*(1), 341–7. http://doi.org/10.1016/j.neuroimage.2010.05.071

Garvert, M. M., Moutoussis, M., Kurth-Nelson, Z., Behrens, T. E. J., & Dolan, R. J. (2015). Learning-Induced plasticity in medial prefrontal cortex predicts preference malleability. *Neuron*, *85*(2), 418–428. http://doi.org/10.1016/j.neuron.2014.12.033

Gawronski, B., Bodenhausen, G. V., & Becker, A. P. (2007). I like it, because I like myself: Associative self-anchoring and post-decisional change of implicit evaluations. *Journal of Experimental Social Psychology*, *43*, 221–232. http://doi.org/10.1016/j.jesp.2006.04.001

Gutchess, A. H., Welsh, R. C., Boduroglu, A., & Park, D. C. (2006). Cultural differences in neural function associated with object processing. *Cognitive, Affective, & Behavioral Neuroscience*, *6*(2), 102–109. http://doi.org/10.3758/CABN.6.2.102

Han, S., & Ma, Y. (2014). Cultural differences in human brain activity: A quantitative meta-analysis. *NeuroImage*, *99*, 293–300. http://doi.org/10.1016/j.neuroimage.2014.05.062

Han, S., Northoff, G., Vogeley, K., Wexler, B. E., Kitayama, S., & Varnum, M. E. W. (2012). A Cultural Neuroscience Approach to the Biosocial Nature of the Human Brain. *Annual*

Review of Psychology, *64*, 120920151208003. http://doi.org/10.1146/annurev-psych-071112-054629

Hare, T. A., Camerer, C. F., Knoepfle, D. T., & Rangel, A. (2010). Value computations in ventral medial prefrontal cortex during charitable decision making incorporate input from regions involved in social cognition. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience*, *30*(2), 583–90. http://doi.org/10.1523/JNEUROSCI.4089-09.2010

Harmon-Jones, E. (2000). Cognitive dissonance and experienced negative affect: Evidence that dissonance increases experienced negative affect even in the absence of aversive consequences. *Personality and Social Psychology Bulletin*, *26*, 1490–1501. http://doi.org/10.1177/01461672002612004

Harmon-Jones, E., Amodio, D. M., & Harmon-Jones, C. (2009). *Chapter 3 Action-Based Model of Dissonance. A Review, Integration, and Expansion of Conceptions of Cognitive Conflict*. *Advances in Experimental Social Psychology* (1st ed., Vol. 41). Elsevier Inc. http://doi.org/10.1016/S0065-2601(08)00403-6

Harmon-Jones, E., Amodio, D. M., & Harmon-Jones, C. (2010). Action-based model of dissonance: On cognitive conflict and attitude change. In *The psychology of attitudes and attitude change* (Vol. 41, pp. 163–181). http://doi.org/10.4324/9780203841303

Herrnstein, R., & Murray, C. (1994). *The Bell Curve*. New York: Simon and Schuster.

Hoshino-Browne, E., Zanna, A. S., Spencer, S. J., Zanna, M. P., Kitayama, S., & Lackenbauer, S. (2005). On the cultural guises of cognitive dissonance: the case of easterners and westerners. *Journal of Personality and Social Psychology*, *89*(3), 294–310. http://doi.org/10.1037/0022-3514.89.3.294

Hyde, L. W., Tompson, S., Creswell, J. D., & Falk, E. B. (2015). Cultural neuroscience: new directions as the field matures. *Culture and Brain*, *3*(2), 75–92. http://doi.org/10.1007/s40167-014-0024-6

Iyengar, S. S., & Lepper, M. R. (1999). Rethinking the value of choice: a cultural perspective on intrinsic motivation. *Journal of Personality and Social Psychology*, *76*(3), 349–366. http://doi.org/10.1037/0022-3514.76.3.349

Izuma, K., Matsumoto, M., Murayama, K., Samejima, K., Sadato, N., & Matsumoto, K. (2010). Neural correlates of cognitive dissonance and choice-induced preference change. *Proceedings of the National Academy of Sciences of the United States of America*, *107*(51), 22014–22019. http://doi.org/10.1073/pnas.1011879108

Janowski, V., Camerer, C., & Rangel, A. (2013). Empathic choice involves vmPFC value signals that are modulated by social processing implemented in IPL. *Social Cognitive and Affective Neuroscience*, *8*(2), 201–208. http://doi.org/10.1093/scan/nsr086

Jarcho, J. M., Berkman, E. T., & Lieberman, M. D. (2011). The neural basis of rationalization: cognitive dissonance reduction during decision-making. *Social Cognitive and Affective Neuroscience*, *6*, 460–7. http://doi.org/10.1093/scan/nsq054

Jenkinson, M., Bannister, P., Brady, M., & Smith, S. (2002). Improved optimization for the robust and accurate linear registration and motion correction of brain images. *NeuroImage*, *17*(2), 825–841. http://doi.org/10.1016/S1053-8119(02)91132-8

Jung, D., Sul, S., & Kim, H. (2013). Dissociable neural processes underlying risky decisions for self versus other. *Frontiers in Neuroscience*, *7*, 15. http://doi.org/10.3389/fnins.2013.00015

Kahnt, T., Heinzle, J., Park, S. Q., & Haynes, J.-D. (2011). Decoding different roles for vmPFC and dlPFC in multi-attribute decision making. *NeuroImage*, *56*(2), 709–715.

http://doi.org/10.1016/j.neuroimage.2010.05.058

Kim, H., & Markus, H. R. (1999). Deviance or uniqueness, harmony or conformity? A cultural analysis. *Journal of Personality and Social Psychology*, *77*(4), 785–800. http://doi.org/10.1037/0022-3514.77.4.785

Kim, H. S., & Sherman, D. K. (2007). "Express yourself": culture and the effect of self-expression on choice. *Journal of Personality and Social Psychology*, *92*(1), 1–11. http://doi.org/10.1037/0022-3514.92.1.1

Kim, K., & Johnson, M. K. (2012). Extended self: medial prefrontal activity during transient association of self and objects. *Social Cognitive and Affective Neuroscience*, *7*(2), 199–207. http://doi.org/10.1093/scan/nsq096

Kim, K., & Johnson, M. K. (2014). Extended self: Spontaneous activation of medial prefrontal cortex by objects that are "mine." *Social Cognitive and Affective Neuroscience*, *9*, 1006–1012. http://doi.org/10.1093/scan/nst082

Kimel, S. Y., Grossmann, I., & Kitayama, S. (2012). When gift-giving produces dissonance: Effects of subliminal affiliation priming on choices for one's self versus close others. *Journal of Experimental Social Psychology*, *48*(5), 1221–1224. http://doi.org/10.1016/j.jesp.2012.05.012

Kitayama, S., Chua, H. F., Tompson, S., & Han, S. (2013). Neural mechanisms of dissonance: An fMRI investigation of choice justification. *NeuroImage*, *69*, 206–212. http://doi.org/10.1016/j.neuroimage.2012.11.034

Kitayama, S., King, A., Yoon, C., Tompson, S., Huff, S., & Liberzon, I. (2014). The dopamine D4 receptor gene (DRD4) moderates cultural difference in independent versus interdependent social orientation. *Psychological Science*, *25*(6), 1169–1177.

http://doi.org/10.1177/0956797614528338

Kitayama, S., Snibbe, A. C., Markus, H. R., & Suzuki, T. (2004). Is there any "free" choice? Self and dissonance in two cultures. *Psychological Science*, *15*(8), 527–33. http://doi.org/10.1111/j.0956-7976.2004.00714.x

Kitayama, S., & Tompson, S. (2015). *A Biosocial Model of Affective Decision Making: Implications for Dissonance, Motivation, and Culture*. *Advances in Experimental Social Psychology* (Vol. 52). http://doi.org/10.1016/bs.aesp.2015.04.001

Kitayama, S., Tompson, S., & Chua, H. F. (2014). Cultural Neuroscience of Choice Justification.

Kitayama, S., & Uskul, A. K. (2011). Culture, mind, and the brain: current evidence and future directions. *Annual Review of Psychology*, *62*, 419–49. http://doi.org/10.1146/annurev-psych-120709-145357

Knutson, B., Rick, S., Wimmer, G. E., Prelec, D., & Loewenstein, G. (2007). Neural predictors of purchases. *Neuron*, *53*(1), 147–156. http://doi.org/10.1016/j.neuron.2006.11.010

Knutson, B., Taylor, J., Kaufman, M., Peterson, R., & Glover, G. (2005). Distributed Neural Representation of Expected Value. *Journal of Neuroscience*, *25*(19), 4806–4812. http://doi.org/10.1523/JNEUROSCI.0642-05.2005

Kriegeskorte, N., Mur, M., & Bandettini, P. a. (2008). Representational similarity analysis - connecting the branches of systems neuroscience. *Frontiers in Systems Neuroscience*, *2*(November), 4. http://doi.org/10.3389/neuro.06.004.2008

Lieberman, M. (2010). Social cognitive neuroscience. *Handbook of Social Psychology*, 143–193. http://doi.org/10.1002/9780470561119.socpsy001005

Ma, Y., Bang, D., Wang, C., Allen, M., Frith, C. D., Roepstorff, A., & Han, S. (2012). Sociocultural patterning of neural activity during self-reflection. *Social Cognitive and*

Affective Neuroscience. http://doi.org/10.1093/scan/nss103

Maldjian, J. A., Laurienti, P. J., Kraft, R. A., & Burdette, J. H. (2003). *An automated method for neuroanatomic and cytoarchitectonic atlas-based interrogation of fMRI data sets*. *NeuroImage* (Vol. 19).

Markus, H. R., & Kitayama, S. (1991). Culture and the Self."Implications for Cognition, Emotion, and Motivation. *Psychological Review*, *98*, 224–253. Retrieved from papers2://publication/uuid/2F58515D-1AB0-43B3-B2EC-0F057A98343C

Markus, H. R., & Kitayama, S. (2003). Models of agency: sociocultural diversity in the construction of action. *Nebraska Symposium on Motivation. Nebraska Symposium on Motivation*, *49*, 1–57.

Markus, H. R., & Schwartz, B. (2010). Does Choice Mean Freedom and Well-Being? *Journal of Consumer Research*, *37*(2), 344–355. http://doi.org/10.1086/651242

McLaren, D. G., Ries, M. L., Xu, G., & Johnson, S. C. (2012). A generalized form of context-dependent psychophysiological interactions (gPPI): A comparison to standard approaches. *NeuroImage*, *61*(4), 1277–1286. http://doi.org/10.1016/j.neuroimage.2012.03.068

Mead, M. (1928). Coming of age in Samoa. *Epcdssocialstudies.Pbworks.Com*, *24*(February), 244–248. http://doi.org/10.2307/2749975

Morel, N., Villain, N., Rauchs, G., Gaubert, M., Piolino, P., Landeau, B., … Chételat, G. (2014). Brain activity and functional coupling changes associated with self-reference effect during both encoding and retrieval. *PloS One*, *9*(3), e90488. http://doi.org/10.1371/journal.pone.0090488

Mur, M., Bandettini, P. A., & Kriegeskorte, N. (2009). Revealing representational content with pattern-information fMRI - An introductory guide. *Social Cognitive and Affective*

Neuroscience, *4*(1), 101–109. http://doi.org/10.1093/scan/nsn044

Na, J., & Kitayama, S. (2012). Will people work hard on a task they choose? Social-eyes priming in different cultural contexts. *Journal of Experimental Social Psychology*, *48*(1), 284–290. http://doi.org/10.1016/j.jesp.2011.09.003

Nili, H., Wingfield, C., Walther, A., Su, L., Marslen-Wilson, W., & Kriegeskorte, N. (2014). A Toolbox for Representational Similarity Analysis. *PLoS Computational Biology*, *10*(4). http://doi.org/10.1371/journal.pcbi.1003553

Nisbett, R. E., Aronson, J., Blair, C., Dickens, W., Flynn, J., Halpern, D. F., & Turkheimer, E. (2012). Intelligence: New findings and theoretical developments. *American Psychologist*, *67*(2), 130–159. http://doi.org/10.1037/a0026699

Northoff, G., Heinzel, A., de Greck, M., Bermpohl, F., Dobrowolny, H., & Panksepp, J. (2006a). Self-referential processing in our brain-A meta-analysis of imaging studies on the self. *NeuroImage*, *31*, 440–457. http://doi.org/10.1016/j.neuroimage.2005.12.002

Northoff, G., Heinzel, A., de Greck, M., Bermpohl, F., Dobrowolny, H., & Panksepp, J. (2006b). Self-referential processing in our brain—A meta-analysis of imaging studies on the self. *NeuroImage*, *31*(1), 440–457. http://doi.org/10.1016/j.neuroimage.2005.12.002

Norton, M. I., Monin, B., Cooper, J., & Hogg, M. A. (2003). Vicarious dissonance: attitude change from the inconsistency of others. *Journal of Personality and Social Psychology*, *85*(1), 47–62. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12872884

Park, B., Tsai, J. L., Chim, L., Blevins, E., & Knutson, B. (2016). Neural evidence for cultural differences in the valuation of positive facial expressions. *Social Cognitive and Affective Neuroscience*, *11*(2), 243–52. http://doi.org/10.1093/scan/nsv113

Pearson, J. M., Hayden, B. Y., Raghavachari, S., & Platt, M. L. (2009). Neurons in posterior

cingulate cortex signal exploratory decisions in a dynamic multioption choice task. *Current Biology : CB*, *19*, 1532–7. http://doi.org/10.1016/j.cub.2009.07.048

Poldrack, R. A. (2012). The future of fMRI in cognitive neuroscience. *NeuroImage*, *62*(2), 1216–1220. http://doi.org/10.1016/j.neuroimage.2011.08.007

Qin, J., Kimel, S., Kitayama, S., Wang, X., Yang, X., & Han, S. (2011). How choice modifies preference: Neural correlates of choice justification. *NeuroImage*, *55*(1), 240–6. http://doi.org/10.1016/j.neuroimage.2010.11.076

Qin, P., Liu, Y., Shi, J., Wang, Y., Duncan, N., Gong, Q., … Northoff, G. (2012). Dissociation between anterior and posterior cortical regions during self-specificity and familiarity: A combined fMRI-meta-analytic study. *Human Brain Mapping*, *33*(1), 154–164. http://doi.org/10.1002/hbm.21201

Riemer, H., Shavitt, S., Koo, M., & Markus, H. R. (2014). Preferences Don't Have to Be Personal: Expanding Attitude Theorizing with a Cross-Cultural Perspective. *Psychological Review*, *121*(4), 619–648. http://doi.org/10.1037/a0037666

Ries, M. L., McLaren, D. G., Bendlin, B. B., Guofanxu, Rowley, H. A., Birn, R., … Johnson, S. C. (2012). Medial prefrontal functional connectivity--relation to memory self-appraisal accuracy in older adults with and without memory disorders. *Neuropsychologia*, *50*(5), 603–11. http://doi.org/10.1016/j.neuropsychologia.2011.12.014

Rogers, B. P., Morgan, V. L., Newton, A. T., & Gore, J. C. (2007). Assessing functional connectivity in the human brain by fMRI. *Magnetic Resonance Imaging*, *25*(10), 1347–1357. http://doi.org/10.1016/j.mri.2007.03.007

Sajonz, B., Kahnt, T., Margulies, D. S., Park, S. Q., Wittmann, A., Stoy, M., … Bermpohl, F. (2010). Delineating self-referential processing from episodic memory retrieval: common

and dissociable networks. *NeuroImage*, *50*(4), 1606–17. http://doi.org/10.1016/j.neuroimage.2010.01.087

Savani, K., Cho, J., Sooyun, B., & Morris, M. W. (2014). Culture and Judgment and Decision Making. In *Blackwell Handbook of Judgment and Decision Making*. Retrieved from http://onlinelibrary.wiley.com.openathens-proxy.swan.ac.uk/book/10.1002/9780470752937

Savani, K., Markus, H. R., & Conner, A. L. (2008). Let your preference be your guide? Preferences and choices are more tightly linked for North Americans than for Indians. *Journal of Personality and Social Psychology*, *95*(4), 861–76. http://doi.org/10.1037/a0011618

Savani, K., Markus, H. R., Naidu, N. V. R., Kumar, S., & Berlia, N. V. (2010). What counts as a choice? U.S. Americans are more likely than Indians to construe actions as choices. *Psychological Science : A Journal of the American Psychological Society / APS*, *21*(3), 391–398. http://doi.org/10.1177/0956797609359908

Schmitz, T. W., & Johnson, S. C. (2007). Relevance to self: A brief review and framework of neural systems underlying appraisal. *Neuroscience and Biobehavioral Reviews*, *31*(4), 585–596.

Sharot, T., De Martino, B., & Dolan, R. J. (2009). How choice reveals and shapes expected hedonic outcome. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience*, *29*(12), 3760–3765. http://doi.org/10.1523/JNEUROSCI.4972-08.2009

Shenhav, A., Straccia, M. A., Cohen, J. D., & Botvinick, M. M. (2014). Anterior cingulate engagement in a foraging context reflects choice difficulty, not foraging value. *Nature Neuroscience*, *17*(9), 1249–54. http://doi.org/10.1038/nn.3771

Singelis, T. M. (1994). The Measurement of Independent and Interdependent Self-Construals.

http://doi.org/10.1177/0146167294205014

Steele, C. M. (1988). The Psychology of Self-Affirmation: Sustaining the Integrity of the Self. *Advances in Experimental Social Psychology*, *21*, 261–302. http://doi.org/10.1016/S0065-2601(08)60229-4

Steele, C. M., & Liu, T. J. (1983). Dissonance processes as self-affirmation. *Journal of Personality and Social Psychology*, *45*(1), 5–19. http://doi.org/10.1037/0022-3514.45.1.5

Stone, J., & Cooper, J. (2001). A Self-Standards Model of Cognitive Dissonance. *Journal of Experimental Social Psychology*, *37*, 228–243. http://doi.org/10.1006/jesp.2000.1446

van der Meer, L., Costafreda, S., Aleman, A., & David, A. S. (2010). Self-reflection and the brain: A theoretical review and meta-analysis of neuroimaging studies with implications for schizophrenia. *Neuroscience and Biobehavioral Reviews*, *34*, 935–946. http://doi.org/10.1016/j.neubiorev.2009.12.004

Varnum, M. E. W., Shi, Z., Chen, A., Qiu, J., & Han, S. (2014). When "Your" reward is the same as "My" reward: self-construal priming shifts neural responses to own vs. friends' rewards. *NeuroImage*, *87*, 164–9. http://doi.org/10.1016/j.neuroimage.2013.10.042

Worsley, K. J., Evans, A. C., Marrett, S., & Neelin, P. (1992). A three-dimensional statistical analysis for CBF activation studies in human brain. *Journal of Cerebral Blood Flow and Metabolism : Official Journal of the International Society of Cerebral Blood Flow and Metabolism*, *12*(6), 900–918. http://doi.org/10.1038/jcbfm.1992.127

Worsley, K. J., Poline, J. B., Friston, K. J., & Evans, A. C. (1997). Characterizing the response of PET and fMRI data using multivariate linear models. *NeuroImage*, *6*(4), 305–19. http://doi.org/10.1006/nimg.1997.0294

Zaki, J., Lopez, G., & Mitchell, J. P. (2014). Activity in ventromedial prefrontal cortex co-varies

with revealed social preferences: Evidence for person-invariant value. *Social Cognitive and Affective Neuroscience*, *9*(4), 464–469. http://doi.org/10.1093/scan/nst005